NCR-days 2004

Research for managing rivers: present and future issues

November 4 – 6

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A.G. van Os (eds.)

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Preface

These proceedings are the product of the NCR-days 2004, held 4-6 November 2004 in Wageningen. The NCR-days are a yearly conference at which mainly young scientists present their ongoing research on a wide variety of fluvial subjects. Since 2000, the NCR-days have been organised in rotation by different institutes represented in the Netherlands Centre for River studies (NCR). With the NCR-days 2004, organised by Alterra, the first lustrum of this event was reached.

The conference centre 'De Wageningse Berg', hosting the NCR-days 2004, is an excellent location for a conference on rivers: it sits on top of a steep hill offering a magnificent view on the river Neder-Rijn and its floodplain (see Photo). In this inspiring setting we welcomed 141 participants, the greatest number since the start of the conference series. Among them were 22 participants giving an oral presentation. Additionally, 24 posters were presented. For the first time, four workshops were organised, with the objective to initiate discussion on how to match 'supply and demand' of research on different issues of present interest. The idea to include workshops in the conference programme was an outcome of the evaluation of the NCR-days 2003, endorsed by the 5 year evaluation of NCR. After two days of presentations and workshops, a field trip to various recent projects on improving environment and safety on the river Neder-Rijn (Fig. 1) was a proper conclusion of the conference.

The 46 contributions (oral presentations and posters) to the conference resulted in the 43 papers in this proceedings volume. The papers have been arranged into sections that basically represent the various sessions of the conference. In the review process, we were helped by members of the NCR Programme Committee: Eelco van Beek, Gerard Blom, Ipo Ritsema, Rob Leuven, Jan Ribberink, Erik Mosselman (replacing Kees Sloff) and Remko Uijlenhoet. They are thanked for their careful work.

We also wish to thank Tine Verheij of the conference agency Routine, Jolien Mans of NCR, the chairmen of the sessions Freek Huthoff, Nadine Slootjes, Saskia van Vuren, Ivo Thonon and Menno Straatsma, the workshop speakers Peter Glas, Almar Otten, Jan Al, Udo Boot and Henk Verkerk, and our keynote speakers Pavel Kabat and Joost de Ruigh. Funding by the Netherlands Organization for Scientific Research (NWO) is gratefully acknowledged.

During the first five years of its existence, the NCR-days have proven to be an attractive platform for exchange of ideas and discussion serving the community of developers and users of expertise on rivers. The challenge for the next lustrum will be to maintain the intimate and informal atmosphere with possibly still increasing numbers of participants. Given the positive experience of 2004, we foresee a bright future for the NCR-days and confidently look forward to the 2005 edition that will be organised by NITG-TNO.

Bart Makaske, Henk Wolfert & Ad van Os

At various righthand pages you will find photographs giving an impression of the NCR-days 2004

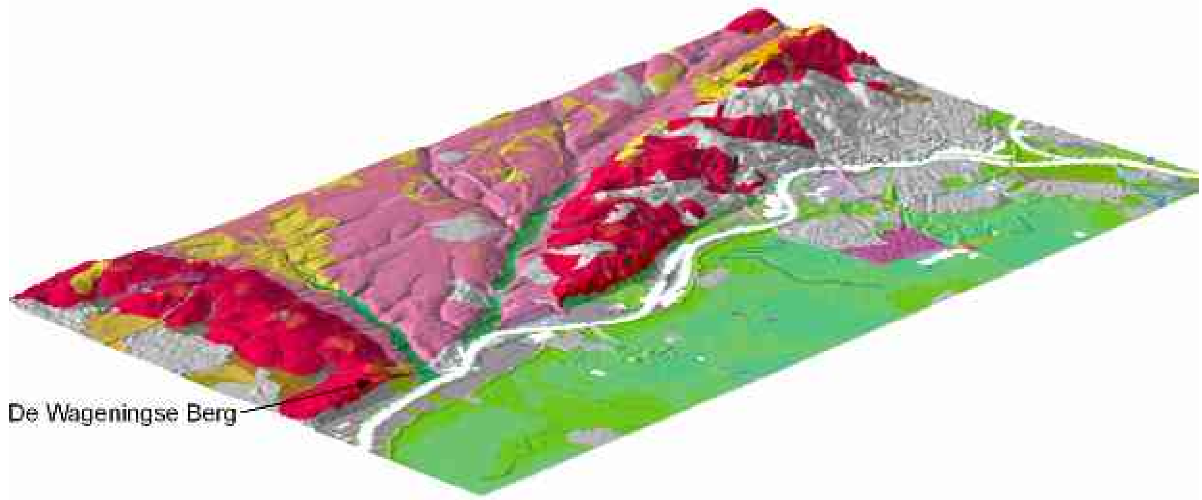

Figure 1. An oblique aerial view on 'De Wageningse Berg', the Neder-Rijn and its floodplain between Arnhem and Wageningen (view looking north-east). The area shown (12.5 x 20 km) also covers the destinations of the field trip after the conference. (based on the Geomorphological Map of the Netherlands, scale 1:50.000 by Alterra).

Contents

Ecology

Sediments, Hydraulics and Morphology

Abstract

NCR is the abbreviation for the Netherlands Centre for River studies. It is a collaboration of nine major scientific research institutes in The Netherlands, which was established on October 8, 1998.

NCR's goal is to enhance the cooperation between the most important scientific institutes in the field of river related research in The Netherlands by:

- Building a joint in-depth knowledge base on rivers in The Netherlands in order to adequately anticipate on societal needs, both on national as well as international level;
- Strengthening the national and international position of Dutch scientific research and education;
- Establishment of a common research programme.

NCR strives to achieve this goal by:

- Committed cooperation, in which the actual commitment of the participating parties is expressed;
- Offering a platform, which is expressed by the organisation of meetings where knowledge and experiences are exchanged and where parties outside NCR are warmly welcomed.

The committed cooperation and collaboration is based on a programme. This programme was first published in October 2000 and was actualised in August 2001.
The platform function is expressed amongst others by the organisation of the so-called annual NCR-days. The publication at hand contains the proceedings of the NCR-days, organised on November 4-5, 2004.

The proceedings of the NCR-days 2004 are sub-titled “Research for managing rivers: present and future issues”.
This is subdivided in the themes (i) Flood Management and Defence, (ii) Hydrology, (iii) Ecology and (iv) Sediments, Hydraulics and Morphology. They cover to a large extend the research which is performed in The Netherlands nowadays.

Samenvatting

NCR staat voor Nederlands Centrum voor Rivierkunde. Het is een samenwerkingsverband dat op 8 oktober 1998 is opgericht door negen wetenschappelijke onderzoekinstituten in Nederland.

Het doel van NCR is het bevorderen van samenwerking tussen de belangrijkste wetenschappelijke instituten op het gebied van rivieronderzoek in Nederland door:

- het opbouwen van een kennisbasis van voldoende breedte en diepte in Nederland omtrent rivieren waardoor adequaat kan worden tegemoet gekomen aan de maatschappelijke behoefte, zowel nationaal als internationaal;
- het versterken van het wetenschappelijke onderwijs en onderzoek aan de Nederlandse universiteiten;
- het vaststellen van een gezamenlijk onderzoekprogramma.

NCR wil dit doel op twee manieren bereiken:

- via *gecommitteerde samenwerking*; hierin komt het daadwerkelijke commitment van deelnemende partners tot uiting;
- via het bieden van een *platform*; deze functie uit zich in het organiseren van bijeenkomsten, waarop kennis en ervaringen worden uitgewisseld; andere partijen zijn daarbij van harte welkom.

De gecommitteerde samenwerking geschiedt op basis van een programma. Dit programma is in oktober 2000 voor het eerst in het Nederlands gepubliceerd en geactualiseerd in Augustus 2001.
De platformfunctie komt onder andere tot uiting in het jaarlijks organiseren van de zogenaamde NCR-dagen. Voorliggende publicatie bevat de "proceedings" van de NCR-dagen die gehouden werden op 4 en 5 november 2004.

De proceedings van de NCR-dagen 2004 dragen de subtitel ""Research for managing rivers: present and future issues", vrij vertaald "Onderzoek ten behoeve van rivierbeheer: heden en toekomst".

De verschillende thema's van de NCR-dagen 2004, (i) Hoogwaterbescherming en beheer, (ii) Hydrologie, (iii) Ecologie en (iv) Sedimenten, Hydraulica en Morfologie, dekken een groot gedeelte van het hedendaagse onderzoek dat in Nederland op rivierkundig gebied wordt uitgevoerd.

NCR-days 2004; Introduction

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The Netherlands Centre for River studies (NCR) is a collaboration of the major developers and users of expertise in the Netherlands in the area of rivers, viz. the universities of Delft, Utrecht, Nijmegen, Twente and Wageningen, UNESCO-IHE, ALTERRA, TNO-NITG, RIZA and WL | Delft Hydraulics. NCR's goal is to build a joint knowledge base on rivers in the Netherlands and to promote co-operation between the most important scientific institutes in the field of river studies in the Netherlands.

NCR has two key functions:

- *Network or platform function*: this function is reflected in the organisation of meetings at which expertise and experience are exchanged; other parties are very welcome to attend.
- *Research-orientated and educational co-operation*: in which a real commitment of the partners is reflected.

To perform its first key function NCR aims to provide an open platform for all people interested in scientific research and communication on river issues.
To that end NCR organises once a year the so-called NCR-days, where on two ongoing consecutive days scientists present their river studies, in order to maximise the exchange of ideas and experiences between the participants and to provide the researchers a sounding board for their study approach and preliminary results. Based on these contacts they can improve their approach and possibly establish additional co-operation.

NCR organised these NCR-days for the fifth time on November 4th and 5th, 2004 in De Wageningse Berg in Wageningen, the Netherlands.
In the publication at hand the presentations and posters presented are summarized.

The statistics of the 2004 days are very satisfying: we reached an all time high as far as number of participants is concerned: some 140 participants distributed evenly over the NCR partners and other institutes and consultancy agencies (Fig. 1).
The development of the participation over the years is given in Fig. 2 (next page).
Also the presentations and posters were reasonably distributed over NCR partners and non-NCR participants
In total 27 oral presentations were given and 25 posters could be seen and discussed. In fact much more presentations were proposed, but the organisers had to limit the amount to 20 (plus 7 key note presentations) to give the participants opportunity for the poster sessions and discussions.

The NCR Programme Committee decided in 2003 to establish the NCR-days Presentation and Poster Awards. They both consist of a Certificate and the refunding of the participation costs for the NCR-days.

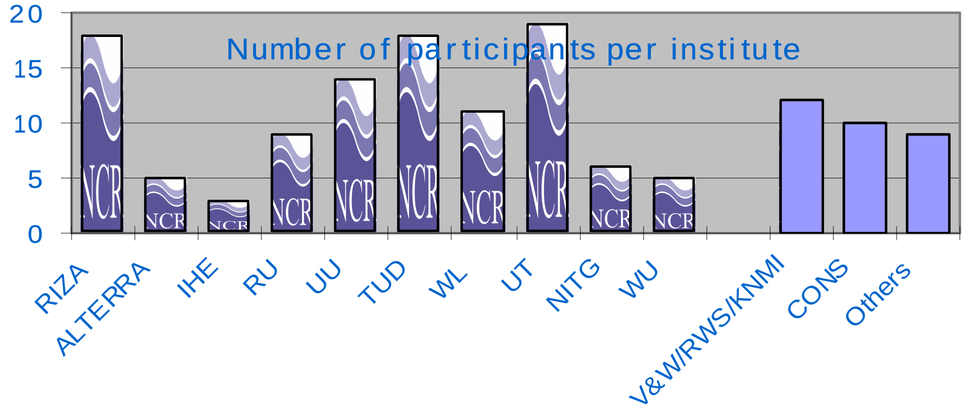

Figure 1. Number of participants per institute

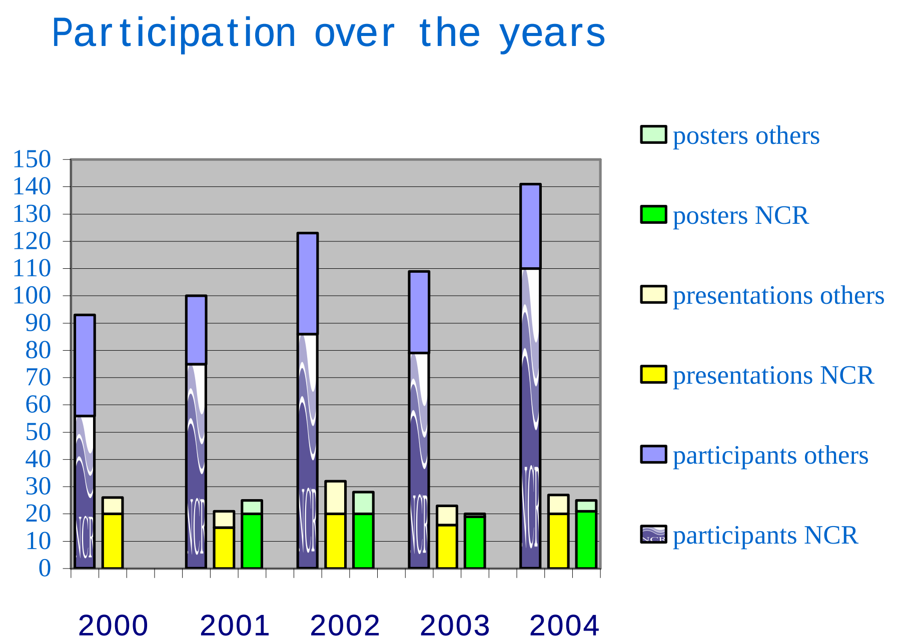

Figure 2. Development of participation over the years

The participants determined the winners. To that end each participant received four evaluation forms (two for a specific presentation and two for a specific poster) at the registration desk. They were selected at random.
The participants took their 'evaluation job' very seriously. This added considerably to the liveliness of the discussions during the intermissions and poster sessions.
The poster sessions are a very important part of the NCR-days. We use the 'Hyde Park Corner approach' where the primary poster authors are given the opportunity in 'two-minute-talks' to give the participants an appetite to come and see the posters and discuss the content with the authors. This worked again very well.

The winners of the NCR-days Awards were announced at the end of the NCR-days.

The NCR-days Presentation Award 2004 (Fig. 3) was won by Roy Frings for her presentation 'Supply-limited transport of bed-load sediment at the IJsselkop' (see page 94).
The NCR-days Poster Award 2004 (Fig. 4) was won by Paul Aalders for his poster 'A 3,000 year discharge simulation in the Meuse basin with a stochastic weather generator and the HBV model' (see page 56).

Figure 3. NCR-days Presentation Award 2004

Figure 4. NCR-days Poster Award 2004

Relating river change, biodiversity and land-use consequences: the Taquari River, Pantanal, Brazil

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Introduction

The Taquari is a tributary of the Paraguay River in south-western Brazil (Fig. 1). One of the problems that has developed in the last thirty years is the permanent flooding of the savannah over an area of 11.000 km^2 on the Taquari alluvial fan in the Pantanal. In this area, an interdisciplinary research project was carried out (within the framework of the Partners for Water research program), which focused on: (1) the analysis and modelling of the ongoing process; (2) the consequences for biodiversity and land use of the lower Taquari floodplain; (3) capacity building for the organisation of integrated river management at the basin level including relevant stakeholders.

The upper parts of the Taquari catchment represent one of the major erosive areas of the highlands around the Pantanal, consisting of sandy soils. According to the local stakeholders this erosive character has resulted in the inundations of the floodplain of the lower Taquari because of silting up of the river channel.

Erosion in the upper catchment is believed to have strongly increased as a result of clearing of the natural vegetation (Fig. 1).

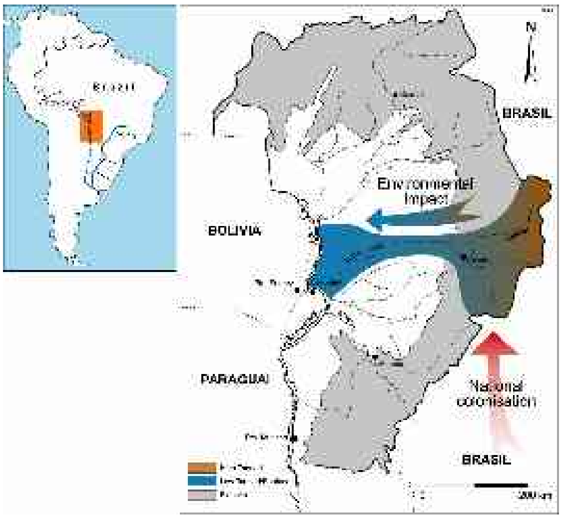

Figure 1. The Taquari River and the Pantanal basin in south-western Brazil. Forest-clearing following 'national colonisation' of the upper Taquari catchment was hypothesized to have environmental impact on the lower Taquari (increased flooding). Hydrological modelling in the present project, however, demonstrated only limited impact of land-use changes on Taquari discharge.

Project approach

The project approach was to carry out joint Brazilian-Dutch research on river management focusing at understanding the Taquari system. Modelling of the river system and its land cover and land use involved construction of a Digital Elevation Model (DEM) and a river discharge model. Geomorphological analysis of remote sensing data and collection of new field data (sampling for ^{14}C dating and grain-size analysis) yielded an impression of river dynamics at various time scales. The DEM was constructed by the Institute for Geo-Information Science and Earth Observation (ITC) and was used by WL | Delft Hydraulics as a basis for a river flow model for the analysis of the river changes. The water input from the Planalto was considered as a given parameter ('black box'): the Taquari at Coxim (Fig. 1) is the only input of surface water into the plains. The DEM and the hydrological model, with important ecological knowledge of EMBRAPA-Pantanal made it possible to develop scenarios on the consequences of the ongoing processes for ecotopes, land use and species.

To provide river managers and stakeholders with insight in the consequences of planning and management options for the river system, it was necessary to analyse both the socio-economic and the eco-hydrological consequences of the changes in the river system. For the analysis of these impacts, socio-economic and ecological scenarios were developed for different hydrological and climatic changes affecting the river system.

The last, and for all institutes involved most difficult, aspect of the project was the integration of socio-economic consequences with the natural processes. Use was made of interviews with stakeholders and analysis of existing economic data. It is supposed that data and knowledge present in the institutions, with farmers and civil society are sufficient to make a first start with the construction of the Decision Support System. In a special workshop the principles of decision-making and the need for a decision unit were discussed as well as the principles of multi-criteria evaluation. Three scenarios (a dry, average, and wet scenario) were evaluated to demonstrate the principles of spatial multi-criteria evaluation.

Results

The results of the project are various. A fundamental product is the DEM of the study area, with an altitude accuracy of 0.10 m (Fig. 2; Maathuis, 2005).

Figure 2. The final DEM of the Taquari River floodplain in the central Pantanal (Maathuis, 2005). Area shown measures ~300 km in width; north is up.

Other basic research products are the reconstructed geomorphological history, and the geomorphological map of the Taquari alluvial fan. The geomorphological analysis (Makaske, 2005) shows that the flooding problems in the area are associated with two major avulsions: the Caronal avulsion on the middle fan and the Zé da Costa avulsion on the lower fan (avulsion is defined as a diversion of river flow from an existing channel onto the floodplain, eventually resulting in a new river main channel). In addition to these two avulsions, many crevasses exist in the levees of the Taquari on the middle and lower fan (Fig. 3).

Our understanding of the hydrology of the study area has considerably increased. A groundwater map and a flooding map of the river basin were produced. Longitudinal and transverse hydraulic measurements were carried out and a discharge model was set up. It was demonstrated that increased discharge of the Taquari River, leading to avulsions and flooding, mostly results from increased precipitation and to a much lesser extent from changes in land use in the catchment (Querner et al., 2005).

As a result of research efforts in various fields, there is now an up-to-date ecotope map for the study area. Much existing ecological knowledge was organised in such a format that it could be included. These data were used for scenario development on the recognition of changes with impact analysis for biodiversity using the OSIRIS-LEDESS model and LARCH species models. Decision support scenarios were worked out in a special workshop in August 2005 and the results were presented and discussed in November 2005 with stakeholders and researchers.

Research can only have an impact on society when it presents a coherent vision on the future of the river basin and if there is a structure for decision making, and a management organisation. The objective of the project was to develop better understanding of the impact of human influences on the Pantanal basin and to be able to understand the functioning of the Upper Paraguay River Basin (UPRB) as a whole. This means that there had to be a strong link between research of ecological and land-use aspects, technology, management and policy. The project helped to identify opportunities for economically feasible use of the system, and for its management (Jongman, 2005). Three important lessons can be learned from this project.

- The erosion and sedimentation processes in the basin are so intense that technical solutions without a river basin management organisation attacking erosion and sedimentation processes are useless.
- Flood pulses are essential ecological processes in rivers for productivity and biodiversity. The comparison between disturbed and undisturbed rivers delivers important knowledge also for river management in Europe.
- Making water management work and sustainable depends on regional co-ordination and political commitment at supra-regional level. Co-operation between sectors and stakeholders appears sometimes difficult as each group is engraved into its own issues, priorities and views. This is not only true for policy makers and research groups, but also for civil society organisations.

References

Jongman, R.H.G. (ed.), 2005. Pantanal-Taquari; tools for decision making in integrated water management. Alterra Special Publication 2005/02, Alterra, Wageningen, 40 p. and CD-ROM.

Maathuis, B., 2005. The Digital Elevation Model. In: R.H.G. Jongman (ed.), Pantanal-Taquari; tools for decision making in integrated water management. Alterra Special Publication 2005/02, Alterra, Wageningen, pp. 48-62 (in final report on CD).

Makaske, B., 2005. Avulsions, flooding and sedimentation in a geomorphological perspective. In: R.H.G. Jongman (ed.), Pantanal-Taquari; tools for decision making in integrated water management. Alterra Special Publication 2005/02, Alterra, Wageningen, pp. 34-47 (in final report on CD).

Querner, E., R. Jonker, C. Padovani, B. Soriano & S. Galdino, 2005. Impact of climate change and agricultural developments in the Taquari River basin, Brazil. In: T. Wagener, S. Franks, H.V. Gupta, E. Bøgh, L. Bastidas, C. Nobre & C. de Oliveira Galvão (eds.), Regional hydrological impacts of climatic change – impact assessment and decision making. Proceedings of Symposium 6, IAHS Scientific Assembly at Foz do Iguaçu, Brazil, April 2005. IAHS Publication 295, pp. 19-25.

Figure 3. A small crevasse in the natural levee of the Taquari River routing water from the main channel (left) to the floodplain (right). Note the remains of sandbags on the foreground, which were used by the local inhabitants to close the entrance of this small channel.

Assessing the relationship between river flows and human well-being; a case study in Bangladesh

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Abstract
Environmental Flow Assessment methods, developed to assess what part of the flow regime should be maintained in a river to protect the river ecosystem, do not include the importance of this river ecosystem for human well-being. This paper discusses a conceptual model to take human well-being into account in Environmental Flow Assessments, and presents the results of applying the model in a case study in Bangladesh.

Introduction
Water resources development may change the flow regime of a river. Changes to the flow regime affect the river ecosystem and subsequently the lifes of the people depending on it. The negative effects of flow regime changes were recognised in the 1950s. Since then, methods to assess Environmental Flow Requirements are being developed.

Environmental Flow Assessments were recently recognised by many international organisations as a tool to ward off social conflict and environmental degradation due to the overexploitation of water in river basins of the world (IUCN, 2004). Environmental Flow Assessments first focussed on specific species and developed towards considering the entire natural ecosystem. People who depend on the goods and services provided by the river ecosystem did not receive much attention. How to take the needs of the people into account in assessing Environmental Flows is the subject of the research presented in this paper.

First, a conceptual model was developed which describes the links between human well-being and river flows (Fig.1). The second step was to test the model in a case study. The results of this case study, carried out in Bangladesh, are the main topic of this paper.

Conceptual model
The conceptual model starts with the total well-being of the stakeholders, which may be partly related to water. The water-related aspects rely on certain river ecosystem goods or services which require a certain flow regime. The required internal flow regime can consist of discharge, water depth and flow velocity at the location where the goods and services are available. The external flow regime is the flow regime at a location where this can be controlled, for example at a dam or a weir. At all levels the context should be considered to understand the importance of a certain flow requirement for people's well-being. The blocks on the right side represent the various people in different roles. A river manager should take the well-being of the stakeholders into account in a river basin plan and direct actors to maintain a certain flow regime.

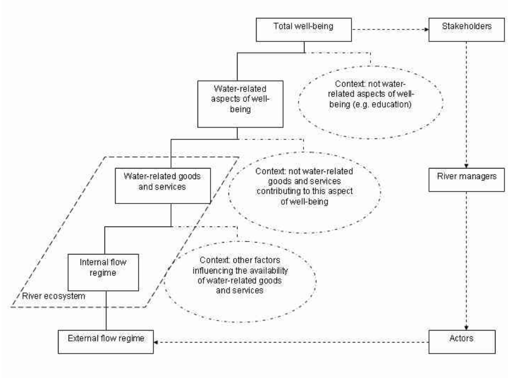

Figure 1. Conceptual model

Case study area and methods
The case study was carried out in the Northeast of Bangladesh along the Surma river (Fig. 2). The Barak river which originates in India bifurcates at the border with Bangladesh into the Surma and the Kushiyara. The area between the two rivers is low-lying and is flooded every year during the monsoon season (Fig. 3). The recession cultivation of rice and the fisheries, which are important income and food provision sectors in the area, are adapted to the rise and fall of the water level. In the selected floodplain area of 400 km^2 live approximately 285 000 people.

In the case study three methods were used: (1) interviews in four villages along the Surma River (Fig. 2); (2) study of reports about the Surma-Kushiyara basin; (3) interpretation of 1-D simulation.

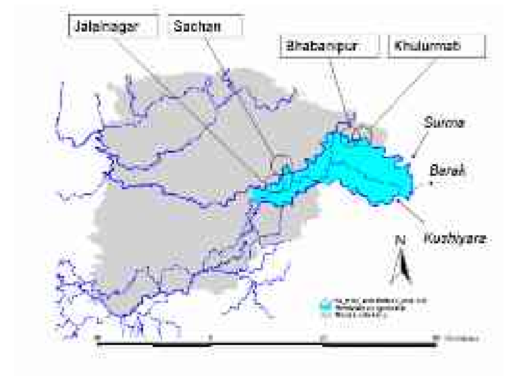

Figure 2. Location of the case study area and selected villages

Case study results

Analysis of the interviews identified recession agriculture, fisheries and domestic use of river water as the main goods and services provided by the ecosystem. Also important are the negative effects of flooding: damage to crops and settlements. Income generation based on ecosystem goods and services is important for 40-80% of the population, 25-70% of the population depends entirely on the natural ecosystem for income. Of this last group of people, 80% is considered to be poor, according to the standards of the villagers. In total, the villagers consider 50% of the population to be poor.

Upscaling to the floodplain area as indicated in Fig. 2 resulted in minimum and maximum water depth requirements for the both the floodplain and the river itself for every month. It was assumed that the objective for defining flow requirements was to maintain current use of ecosystem goods and services. The 1-D simulation results were used to calculate to what extent the floodplain and river area met these requirements.

Table 1 shows the result of the 1-D simulations for the floodplain area. For the year 2000-2001 the requirements on the floodplain are met for all purposes except Aman paddy cultivation. For Aman paddy cultivation only 20% of the required land was available. The main restriction which causes this low availability is the minimum requirement of 5 cm water depth in August and September, while a large area remained dry in the year 2000-2001.

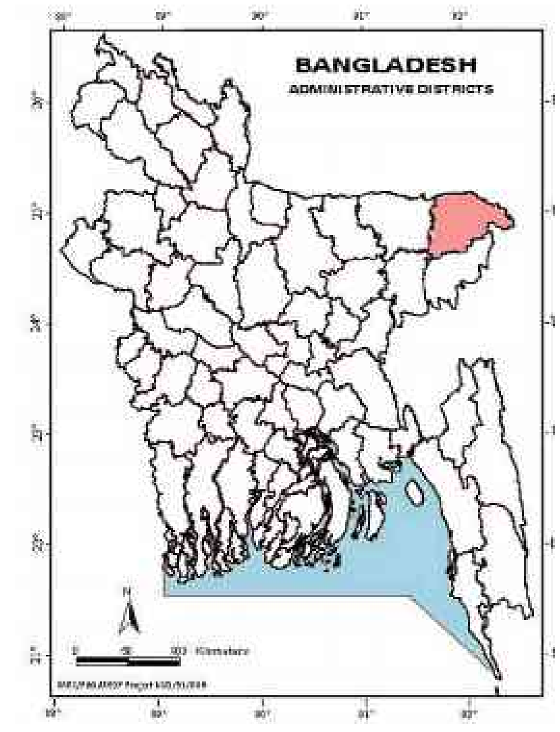

Figure 2. Location of the case study area and selected villages

Conclusions

- The main ecosystem goods and services of the Surma-Kushiyara floodplain are the enabling of cultivation and the provision of fish, which generate food and income for the population. Flooding is the main characteristic to sustain the current use of the river ecosystem, direct use of the river is less important. Although flooding is important for agriculture and fisheries, most of the people prefer to have no flood, because depth and timing of flooding are unpredictable.
- Concerning the methods used in the case study, it can be concluded that interviews help to understand what people use and how important this is for their well-being. To understand the relationship between the (internal) river flow regime and the availability of ecosystem goods and services, expert knowledge is, however, required.
- The conceptual model proved useful for understanding the relationships between people, the river ecosystem and the flow regime. For a thorough understanding of the importance of the river flow regime for human well-being it is essential to consider the different levels of the context as indicated in the conceptual model.

Figure 3. Cross-section of Surma-Kushiyara rivers and floodplain

Reference

IUCN, 2004. International organisations accept 'environmental flows' as solution to social confict over water. Electronic news release IUNC Water & Nature Initiative, 19 Aug. 2004. IUCN, Gland, Switzerland.

Table 1. Comparison of floodplain requirements and simulation results.

Function	Period	Available area (ha)	Required area (ha)	Percentage of requirement met
Aus paddy	April - June	28,389	8,996	316
Aman paddy	July-November	3,174	14,171	22
Boro paddy	December - April	4,358	4,316	101
Vegetables	All year	21,039	1,258	1,672
Over-wintering of fish	October - May	4,030	18	22,389
Spawning of fish	June-September	13,968	1,463	955

Climate change and adaptive water demand

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Introduction

Impacts of global climate change impose pressure on human-environment systems. The agricultural sector is particularly vulnerable. In response to changes in water availability, farmers might change their activities. The research focus is on agricultural land-use changes that influence water demands. System dynamics are represented in a simulation model that helps to explore effects of water management strategies in the near future. Subject of study is the public irrigation area of Icó-Lima Campos in the Jaguaribe River Basin in Ceará, Brazil (Fig. 1). In this research, complexity theory (Axelrod, 1997) and the concept of Common-Pool Resources (Ostrom et al., 1994) are guiding principles for the description of the complex human-environment system.

Figure 1. Lower right: Ceará in the world. Lower left: Icó-Lima Campos area and Orós reservoir from space.

Methods

The research methodology is divided into the five steps described below.

1. Collection of quantitative data. Both remote sensing techniques and statistical methods are applied to analyse system dynamics in recent history.
2. Collection of qualitative data in the case-study area. Farmer-heuristics with respect to decision-making on land-use change are formulated.
3. Building a Multi-Agent Simulation (MAS) model. In this research, Agent-Based Modeling (ABM) for land-use and cover change (Axelrod, 1997; Pahl-Wostl, 2002; Parker et al., 2002; Hare & Deadman, 2004) adds value to the assessment of agricultural vulnerability to droughts by confronting individual farmer heuristics to an environment that is evolving through system dynamics (Fig. 2).
4. Model calibration and validation. A time series of remote sensing images and interviews with experts are used. A comparison of the case-study area to the Morada Nova area (upper right in Fig. 1) will also be done.
5. Exploring future developments. The resulting MAS tool will be used to explore possible future developments in land use and evaluate water management strategies.

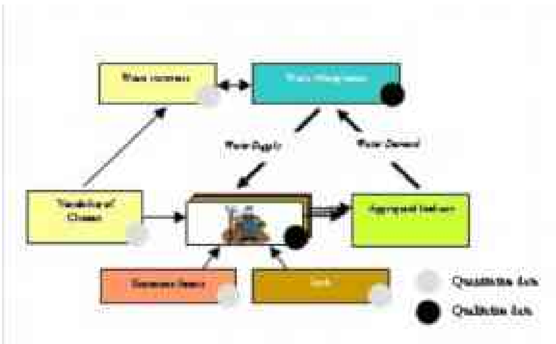

Figure 2. Farmer decision-making on land-use change under influence of system dynamics.

Results

Trends in crop cultivation that suggest adaptive responses to droughts were found. These changes might be directly or indirectly triggered by drought. Between 1990 and 2002 some interesting changes in aggregated local water demand emerged. Figure 3 shows local effective precipitation (a), water volumes in a regionally strategic reservoir (b), changes in local crop cultivation (c) and the corresponding changes in water demand (d).

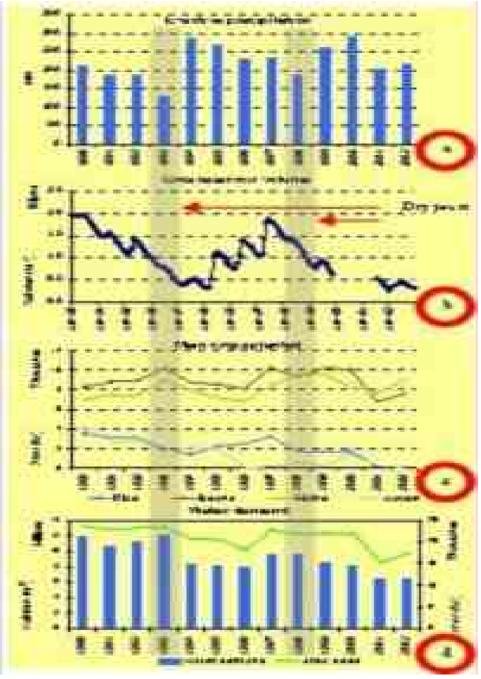

Figure 3. Recent changes in Municipio Icó (from www.sidra.ibge.gov.br).

Conclusions

A drastic decrease in water demand emerged recently. The underlying system dynamics are related to individual and collective farmer decision-making. This justifies taking step two and model system dynamics through Multi-Agent Simulation.

References

Axelrod, R., 1997. The complexity of cooperation: agent-based models of cooperation and collaboration. Princeton University Press, Princeton, 248 p.

Hare, M. & P. Deadman, 2004. Further towards a taxonomy of agent-based simulation models in environmental management. Mathematics and Computers in Simulation 64, pp. 25-40.

Ostrom, E., R. Gardner & J. Walker, 1994. Rules, games and common-pool resources, University of Michigan Press, Ann Arbor, 392 p.

Pahl-Wostl, C., 2002. Agent based simulation in integrated assessment and resources management. In: A. Rizzoli & T. Jakeman (eds), Integrated assessment and decision support. Proceedings of the 1st biennial meeting of the International Environmental Modelling and Software Society, Vol 2, pp. 239-250.

Parker, D.C., T. Berger, & S.M. Manson, 2002. Agent-based models of land-use/land-cover change; report and review of an international workshop, October 4-7, 2001. LUCC Report Series 6, LUCC Focus 1 Office, University of Indiana, Bloomington, 124 p.

Resilience of the lowland part of the Mekong River

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Abstract
The paper studies the usefulness of the resilience concept for flood risk management of the lowland part of the Mekong River. The paper argues that applying resilience is useful because it results in more insight into the relationships between floods and the socio-economy and in more and better solutions for flood risk management.

Introduction
The application of the resilience concept to flood risk management is expected to result in new visions and improved strategies. Resilience, and its opposite, resistance, are both system characteristics. Applying these concepts in flood risk management thus requires a systems approach. Flood risk management systems are defined as a combination of the lowland river and the adjacent flood-prone area with both its physical and socio-economic characteristics (De Bruijn, 2004). The resistance of this system determines which discharges can still be discharged through the river without causing floods, while the resilience determines the ease of the system to recover from floods. In order to evaluate the usefulness of the resilience concept, it has been applied to the lowland part of the Mekong River in Cambodia.

The main question of the case study reads: *what is the current resilience of the lowland part of the Mekong River Basin and how do different strategies affect the system and its reactions to the discharge regime?*

In the Mekong flood risk management system, the socio-economy and floods are strongly related. Normal annual floodings in the monsoon season do not cause damage, because the system is so much adapted to the annual flood pulse, that floods can be regarded essential for the well-functioning of the socio-economy. However, extreme floods (e.g. 1996, 2000, 2001 and 2002) caused lots of damage and casualties. In the future these impacts are expected to rise, because the area is developing fast, population is expected to double in the next 50 years and also the flood frequencies are expected to increase.

Quantifying resilience
Resilience cannot be measured, but it can be quantified by indicators (De Bruijn, in press). De Bruijn (2004a) explains that resilience and resistance reflect the reaction of a system to peak discharges. The indicators therefore cover the three aspects that describe a reaction of the system to peak discharges: *amplitude* which is the severity of the reaction to peak discharges, the *graduality* of the increase of reaction to increasingly severe peak discharges and the *recovery rate* from floods. As an indicator for the amplitude of the reactions to the whole regime of peak discharges the expected annual damage (EAD) can be used. The graduality is assessed by a comparison of the percentual increase of damage and discharge. To assess the recovery rate, the recovery capacity of the system is analysed (De Bruijn, in press).

To determine the indicator values for the Mekong River, first the peak discharge probabilities and the peak discharge volumes and durations were analysed. Secondly, a number of discharge events were simulated with a quasi-2D Mike11 model (Fujii et al., 2003). Thirdly, a damage module was developed to quantify the damage corresponding with these discharge events. Finally, a recovery capacity analysis was performed.

Results
The resilience of the Mekong system is not as high as expected. The EAD of the lowland part of the Mekong River Basin is high: 12 M€/yr or 1 M€/inhabitant. (The EAD of the Netherlands' Rhine is 5 M€/yr or 0.28 M€/yr per inhabitant). The graduality of the increase of damage with increasing peak discharges is 0.79, however, which is comparatively high. The Lower Rhine River, for example, has a graduality of 0.25. The recovery capacity of the Mekong is not high, because the economic and social characteristics of the system limit recovery. The recovery capacity scores a 6 only on a scale from 1 to 10, whiles the Rhine in contrast, scores a 9.

Future
In the future economic growth, population increase and an increase in peak discharges are expected. Because flood risk management strategies and economic developments are difficult to separate, three storylines of three

alternative futures were developed, which combine socio-economic development scenarios and flood risk management strategies: (1) continuation of current flood risk management strategy; (2) agricultural development combined with a resilient flood risk management strategy; (3) rapid economic development combined with a more resistant flood risk management strategy.

The first future results in a decreased resilience because the EAD increases significantly. The second future involves agricultural development (Fig. 1), an improved flood early warning system and a stepwise improvement of water management including irrigation, drainage and flood management. This results in an increased recovery rate, while the EAD and graduality do not change significantly. In the third future, the world's large donors such as the JICA, ADB and the World Bank finance a Flood Action Plan consisting of embankments. Agriculture changes to a more export focused agriculture and industrialisation and urbanisation occur.

Figure 1. About 80% of the population is farmer. Rice is the most important crop in Cambodia.

This future results in an increased EAD, decreased graduality, and a reduction of the recovery rate. Evaluation of the three futures showed that the resilience strategy is very promising: this strategy enhances socio-economic development whilst not harming nature, land scenery or increasing the sensitivity of the system to uncertainties. The resistant future results in increased economic opportunities but also in an increased flood risk, and it negatively affects nature and land scape. Besides, it makes the system more sensitive to uncertainties.

Conclusions

- The current resilience of the Mekong is not as high as expected. The graduality is very high indeed, but the amplitude is also high and the recovery rate is low. Because frequent floods cause significant damage, the amplitude of the reaction to the seasonable discharge patterns is high. The low recovery rate is mainly caused by poverty.
- The assessment of the resilience of this system showed that even in systems that seem wholly adapted to annual floods, resilience is not necessarily high.
- The resilience future looks promising, in comparison to the resistance strategy. Since the resilience strategy can be implemented step by step, is cheaper than the resistance strategy and has advantages for agriculture and fishery, it is certainly a strategy worth considering for the future.
- Adopting a systems approach and considering the whole range of peak discharges resulted in a better insight in the flood risk management of the Mekong River. Because it takes into account more aspects of a system's reactions to a whole range of peak discharges, it helps to identify more and other solutions.

References

De Bruijn, K.M., 2004. Resilience and flood risk management. Water Policy 6, pp. 53-66.

De Bruijn, K.M., in press. Resilience indicators for flood risk management systems of lowland rivers. International Journal of River Basin Management 2 (3).

Fujii, H., H.Garsdal, P. Ward, M. Ishii, K. Morishita & T. Boivin, 2003. Hydrological roles of the Cambodian floodplain of the Mekong River. International Journal of River Basin Management 1 (3), pp. 1-14.

Parker, D.J. (ed), 2000. Floods, Volume I. Routledge, London.

Transboundary effects of extreme floods on the Lower Rhine

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Abstract
Under extreme conditions extreme peak discharges can develop in the Rhine catchment area. At discharges between 11000 m^3/s and 16000 m^3/s large-scale flooding occur along the Lower Rhine in Germany. When dikes overflow or break flows parallel to the Rhine will develop, also resulting in the flooding of areas with a higher protection level. In case of large-scale flooding along the Lower Rhine the peak discharge at Lobith is reduced. Under extreme discharge conditions planned flood-reduction measures in Germany have little effect on the discharge (and water level) at Lobith.

Figure 1. Research area and study area (circle).

Introduction
After the floods of the Rhine in 1993 and 1995 three parties signed a Joint Declaration on Co-operation in the field of flood protection in 1997. These parties were: (1) the Province of Gelderland (The Netherlands); (2) the Ministry of Transport, Public works and Water Management (The Netherlands); (3) the Ministry of Environment and Nature Conservation, Agriculture, and Consumer Protection of North Rhine – Westphalia (Nordrhein-Westfalen) (Germany).

To investigate the effects of extreme floods of the Rhine in Nordrhein-Westfalen the project ‘Transboundary effects of extreme floods at the Lower Rhine’ was commissioned at the end of 2001. Transboundary refers to the boundary between Germany and the Netherlands.

The project was executed by the Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling (RIZA) in Arnhem, the Provincie Gelderland, the Landesumweltamt (LUA) in Düsseldorf, and the Bundesanstalt für Gewässerkunde (BfG) in Koblenz. Under the project title ‘Extreme flood and flood protection along the Rhine (FAR)’ this project was co-funded by the EU-Interreg IIIB North West Europe programme (Lammersen, 2004).

Objectives
Goal of this project was to answer the questions below.

- How much water can be expected in the study reach (Fig. 1) from the Rhine catchment under extreme conditions (at Andernach and Lobith)?
- What is the discharge capacity of the Lower Rhine?
- What happens on the Lower Rhine when the discharge capacity is exceeded?
- What are the effects of flood reduction measures?

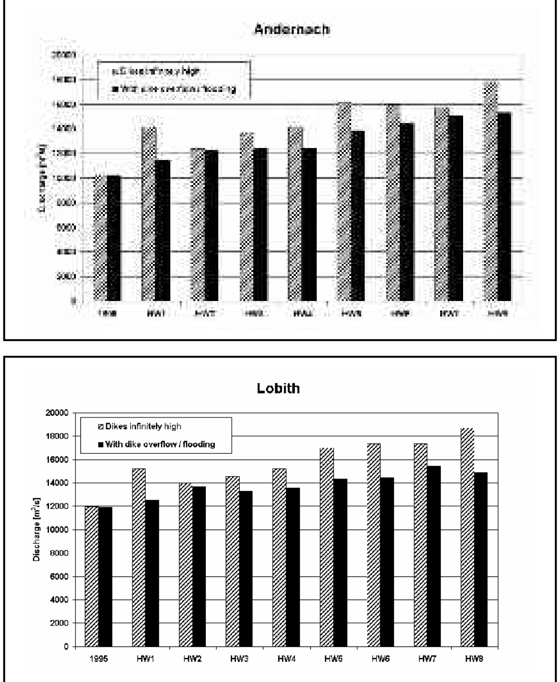

Figure 2. Discharge at Andernach and Lobith, with and without dike overflow, for the eight most extreme discharge waves.

Research method

A stochastic weather generator, developed by KNMI, was used to produce an artificial time series of 1000 year of precipitation and temperature. The input consisted of 30 years of measured meteorological data of 34 different weather stations in the Rhine catchment area. The generated time series, with the same statistics as the historical data, was then put into a rainfall-runoff model covering the whole Rhine basin (HBV) and was transformed into discharge. A selection was made of the 16 most extreme events, based on the HBV results at Andernach and Lobith (Fig. 1). These 16 extreme events were then put into a 1-dimensional flood routing model to compute the 16 highest discharge waves at Andernach in a more accurate way. This part of the project was carried out by the BfG.

With the two most extreme discharge waves at Andernach flood simulations have been performed using the 2-dimensional model Delft-FLS. A Delft-FLS model was made of the Rhine downstream of Andernach (Rhine-km 642) using a 100 m x 100 m grid on top of a digital terrain model. In this model dikes and flood walls were modelled as grid cells. When the water level reaches the dike level a dike collapse occurs. In case of a flood wall, or a natural levee, the floodwall or levee simply overflows and no collapse is simulated. Two situations have been considered: the year 2002 and 2020, with the dike levels of 2002 and 2020 respectively. The input of the 2D-model consisted of the discharge at Andernach and the tributaries of the Rhine. The output consisted of information about locations of a dike collapse or an overflow, flow into the protected area, flood patterns inside the protected area, effect on the discharge wave and finally the discharge capacity of the Rhine. This part of the project was carried out by the Province of Gelderland.

The results of the 2D flood simulations were then transferred to a 1-dimensional SOBEK-model. Each dike collapse or overflow was modelled as a retention basin. Parameters like surface area, capacity, inflow and outflow were based on information from the Delft-FLS model. Using the SOBEK-model the effect of flood reduction measures in Nordrhein-Westfalen was studied. Computations were made with the eight most extreme discharge waves, with and without dike collapse or overflow. Two situations have been considered: the year 2002 and 2020, with the flood reduction measures finished in 2002 and 2020 respectively. This part of the project was carried out by RIZA and LUA.

Figure 3. Flooding along the Lower Rhine (situation 2002)

Results

Under extreme conditions extreme discharges can develop in the Rhine catchment area, up to 17800 m^3/s at Andernach and 18700 m^3/s at Lobith, when dike overflows are not considered. When dike overflows on the Upper Rhine and Lower Rhine are taken into account these numbers reduce to 15300 m^3/s at Andernach and 15500 m^3/s at Lobith (Fig. 2).

At discharges between 11000 m^3/s and 16000 m^3/s large-scale flooding occurs along the Lower Rhine (Fig. 3). First areas along the southern part of the Lower Rhine will be flooded (from Bonn/Köln to Düsseldorf/Dormagen), and at higher discharges also areas along the middle part of the Lower Rhine (from Düsseldorf/Dormagen to the mouth of the Ruhr River). Further downstream no flooding occurs in that situation, except for near Emmerich. In the present situation the flood wall at Emmerich is too low and transboundary floods can occur at discharges exceeding 14000 m^3/s. In 2020, when the flood wall will have been raised, no transboundary flooding can occur anymore. When dikes collapse or overflow, flows parallel to the Rhine will develop, also resulting in the flooding of areas with a higher protection level. In case of large-scale flooding on the Lower Rhine the peak discharge at Lobith is reduced (Fig. 4). At some locations the water flows back into the river (bypasses; Fig. 5).

The planned flood reduction measures in Nordrhein-Westfalen are most effective in case of floods equal to the flood of 1995 (~12000 m^3/s at Lobith), but have little effect under extreme conditions (Fig. 5). Measures in Germany affect the water levels in the Netherlands and the other way around. Measures along the Lower Rhine in Germany reduce the maximum water levels in the Netherlands between 0 and 0.06 meter (Fig. 5). The measures in the Netherlands have a decreasing effect in upstream direction (as far as Ruhrort), with a maximum water level reduction of 0.30 meter at the German-Dutch border.

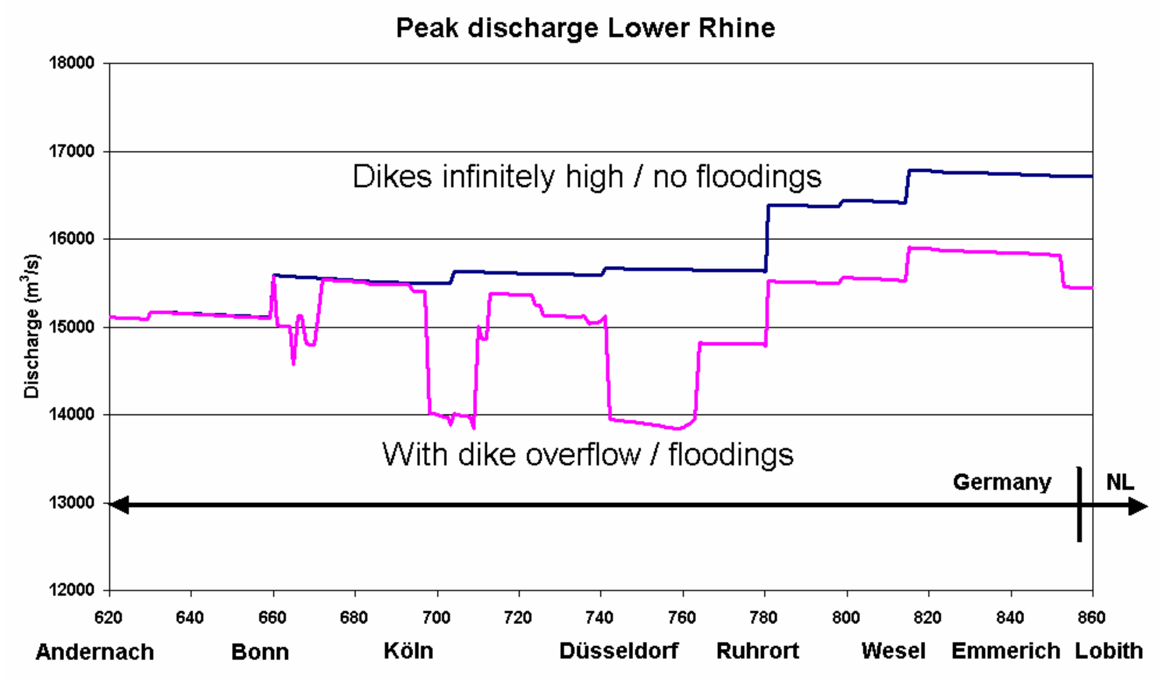

Figure 4. Maximum discharge with and without dike overflow (situation 2002, situation with dike overflow on Upper Rhine).

Final remarks

Co-operation between upstream and downstream areas is crucial in the future, since the river Rhine has no boundaries. As a result of this study there is a discussion about the possibilities for optimizing some of the planned retention basins, i.e. to deploy these retention basins at more extreme conditions (higher flood levels than in 1995). Presently, additional large-scale dike improvements along the Lower Rhine are not considered.

Acknowledgements

Acknowledgements go the German – Dutch flood study group for their supervision and trust and all colleagues at the Bundesanstalt für Gewässerkunde, Landesumweltamt NRW, Provincie Gelderland and RIZA who contributed to the success of this project.

Reference

Lammersen, R., 2004. Grensoverschrijdende effecten van extreem hoogwater op de Niederrhein, Eindrapport. Provincie Gelderland / Rijkswaterstaat Directie Oost-Nederland, Arnhem, 159 p.

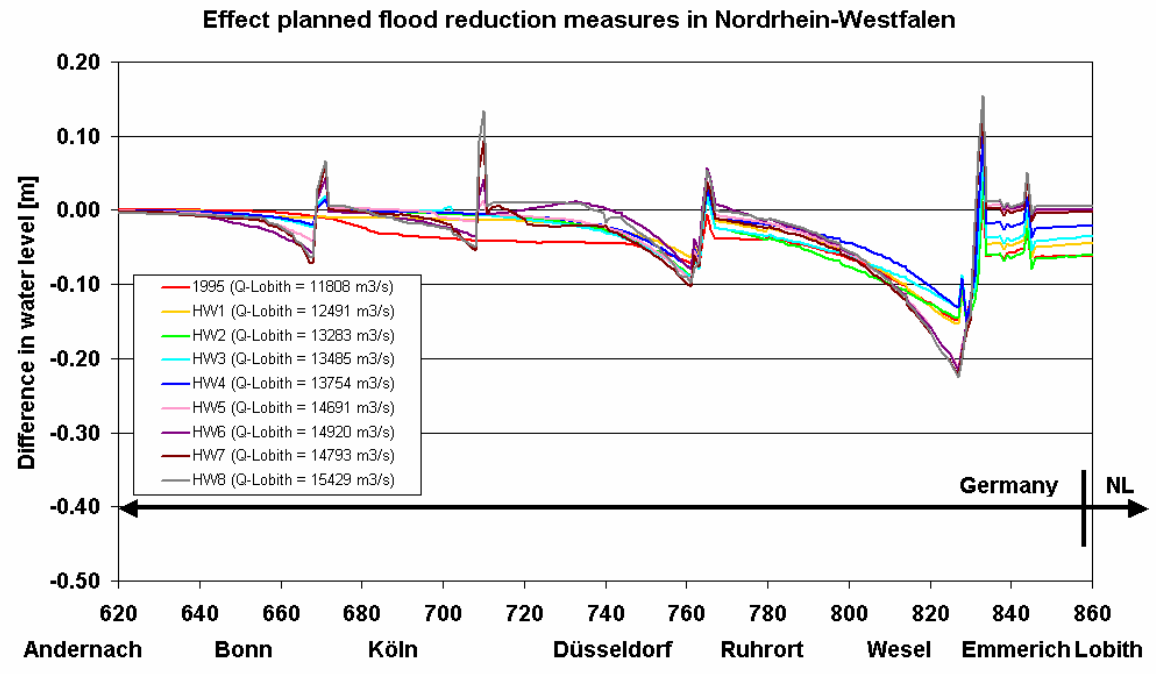

Figure 5. Effect of planned flood reduction measures in Nordrhein-Westfalen

Putting the cyclic rejuvenation strategy into practice: symbiosis between safety and nature

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Abstract
Unbridled growth of shrubs and forests in the nature restoration projects of the regulated Meuse River and Rhine River floodplains, reduce the water discharge capacity beyond acceptable levels. To meet both hydraulic and ecological conditions a new floodplain management strategy will be further elaborated and applied to the Beuningen floodplain (300 ha; Waal River). This management strategy is referred to as Cyclic Floodplain Rejuvenation (CFR) and comprises new institutional arrangements, periodic (cyclic) interventions in the morphology and vegetation of the floodplains and the application of innovative management techniques. The research project is funded by the national research program 'Living with Water'.

Introduction
Since the publication of Plan Ooievaar (De Bruin et al., 1987) the land use of many floodplains along the Meuse and Rhine branches in the Netherlands has been transformed from agriculture to nature management. Although the implementation of this policy can be considered as a success, the vegetation development in some floodplains causes a dangerous decrease of the water discharge capacity (Jesse, 2004).

Within the BSIK-research program 'Living with Water' this project is defined to develop and apply a management strategy that combines both nature and safety objectives. The research project is also a building stone of an international and more comprehensive InterregIIIb-project named 'Freude am Fluss'. The 'Freude am Fluss' project focuses on changes in land use via local initiatives, new market mechanisms and technical innovations. These changes in land use will generate more space for the river and the riparian vegetation but also requires a new view on management. The 'Freude am Fluss' project is carried out by French, German and Dutch governmental organisations, academic institutions and consultants.

Case-study Beuningen floodplain, Waal River
Since 1991 the shift from agriculture to nature restoration has been carried out successfully in the Beuningen floodplain (300 ha; Waal River). However, since this transformation the growth of shrubs and trees gradually exceeded the standard value of hydraulic roughness. Figure 1 shows the increase in hydraulic roughness due to vegetation development between 1985 and 2003. As a consequence, the maximum water level linked to the standard maximum water discharge in this river section increased by 5.5 cm (Mannaerts, 2004). This causes an unacceptable situation. In cooperation with the river and nature managers, it was decided to further elaborate and apply a new management strategy to the Beuningen floodplain to compensate for the increased hydraulic roughness without affecting the ecological values. This new management strategy is named Cyclic Floodplain Rejuvenation.

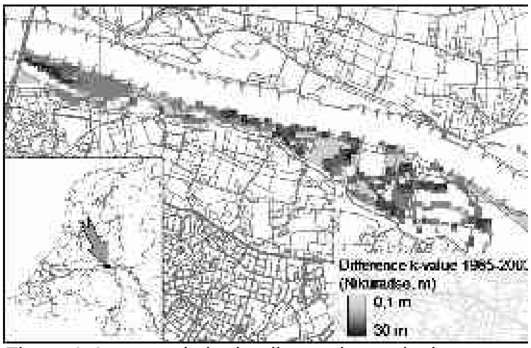

Figure 1. Increase in hydraulic roughness in the Beuningen floodplain, 1985-2003

The new management strategy: Cyclic Floodplain Rejuvenation
In this research 'Cyclic Floodplain Rejuvenation' (CFR) is considered as the system of natural processes in non-regulated rivers that is responsible for building up and breaking down morphology and vegetation. The main processes are erosion, sedimentation and vegetation succession.

In natural rivers the combined action of these processes results in cyclic rejuvenation of morphology and vegetation, and therefore in a natural regulation of the discharge capacity (Smits et al., 2000).

In regulated rivers like the Rhine branches these natural processes cannot act freely because of the presence of for instance dams, weirs, dikes and groynes. As a consequence the natural rejuvenation cycle is broken, and vegetation tends to develop to the climax-stage (forest). The result of this development is an increase of hydraulic roughness, and subsequently an increase of the risk of flooding (Duel et al., 2001; Baptist et al., 2004).

The basic idea of the CFR-strategy is to ‘repair’ the broken rejuvenation cycle by human interventions. Therefore we have to understand the natural rejuvenation processes and if possible, imitate them. In practice, this means setting back succession stages to a pioneer situation (e.g. removal vegetation, lowering floodplains or digging side channels).

The CFR-strategy can contribute to re-establish the discharge capacity, because normally pioneer stages have a lower hydraulic roughness (Van Velzen et al., 2003). The CFR-strategy will also result in more variation of succession stages, and therefore in a higher biodiversity. These are the two main reasons that the CFR-strategy is a promising solution for the realisation of a symbiosis between safety and nature. Besides, the CFR-strategy provides also opportunities for sand or gravel excavations which can reduce the management costs.

In summary, applying the CFR strategy to nature restoration projects in floodplains may realise a symbiosis between safety and nature. However, many knowledge gaps still need to be filled before this new management strategy can be applied and scaled up to entire river sections. The most important knowledge gaps have been identified and incorporated into this research project named ‘Symbiosis between Safety and Nature’.

The planned research activities (2004-2008) address the following issues: (1) institutional arrangements of floodplain and river management; (2) spatial and temporal application of the CFR strategy; (3) cost-effective, innovative management techniques.

Institutional arrangements

During the last two centuries the responsibilities and management tasks of the floodplains in The Netherlands has hardly been changed. However, because of large scale transformation of agricultural use of floodplains to nature management and the upcoming measures within the context of the national flood defence project ‘Room for Rivers’, a new and dynamic situation has evolved. This requires a thorough analysis and possible adjustments of the existing institutional arrangements between involved stakeholders.

Spatial and temporal application of the CFR-strategy

Because the strategy implies periodic (cyclic) interventions at different locations, the spatial and temporal application of CFR-measures is important. The preliminary study activities focused on the Beuningen floodplain and demonstrated that various scale levels need to be addressed:

- studying the ecological aspects should involve the river section on both sides of the river between Nijmegen and Tiel (ca. 40 km);
- considering the hydraulic effects of CFR interventions, solutions for solving the problems in the Beuningen floodplain can be searched up to ca. 15 km downstream;
- an analysis of the institutional arrangements has to be carried out at the local, regional and national scale.

Cost-effective, innovative techniques

As stated, within the CFR-strategy interventions are necessary on a regular basis. Therefore the development of cost-effective techniques is crucial for a successful implementation of this strategy. The case-study of the Floodplains Beuningen focuses on CFR-interventions realised by applying cost-effective, innovative techniques. For example a combination between sub-surface sand excavation techniques and removal of floodplain vegetation will be investigated. Another promising technique is the use of a transformed agricultural machine to remove young trees effectively.

Deliverables of the project

The ‘Living with Water’ research project ‘Symbiosis between Safety and Nature’ will generate the following deliverables in 2008:

- handbook CFR-strategy for river and floodplain managers, focusing on concrete interventions measures, planning in space and time and organisational and logistic recommendations;
- design and realisation of CFR-interventions in the Beuningen floodplain

which will result in a river management permit delivered by the river manager;

- a series of scientific reports and articles in peer reviewed scientific journals dealing with nature management, institutional arrangements and technical innovations in floodplain management.

References

Baptist, M.J., W.E. Penning, H. Duel, A.J.M. Smits, G.W. Geerling, G.E.M. van der Lee & J.S.L. van Alphen, 2004. Assessment of cyclic floodplain rejuvenation on flood levels and biodiversity in the Rhine River. River Research and Applications 20(3), pp. 285-297.

Duel, H., M.J. Baptist & W.E. Penning (eds.), 2001. Cyclic floodplain rejuvenation; a new strategy based on floodplain measures for both flood risk management and enhancement of the biodiversity of the river Rhine. NCR-Publications 14-2001, 72 p.

Jesse, P., 2004. Hydraulische weerstand in (natuur) ontwikkeling. De verandering van de hydraulische ruwheid van acht natuurontwikkelingsprojecten, april 2004. RIZA-werkdocument 2003.124X, RIZA, Arnhem.

Mannaerts, J.J.H.M., 2004. Beuningse Uiterwaard - Rivierkundige toets 2003. Rijkswaterstaat, Directie Oost Nederland, Arnhem, 10 p.

Smits, A.J.M., P. Nienhuis & R. Leuven (eds.), 2000. New approaches to river management. Backhuys, Leiden.

Van Velzen, E.H., P. Jesse, P. Cornelissen & H. Coops, 2003. Stromingsweerstand vegetatie in uiterwaarden. Deel 1 Handboek versie 1-2003. RIZA-rapport 2003.028, RIZA, Arnhem.


"2003 dry summers" in Europe
"2002 flooding" in Europe

Rijnstrangen/Lingewaarden: a tap for the Rhine branches

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Introduction

The high waters of 1993 and 1995 gave rise to a new policy of the Dutch Rhine branches 'Ruimte voor de Rivier' ('Room for the river'), consisting of measures creating more discharge capacity in the river system. Staatsbosbeheer has developed another option for this, 'Lonkend Rivierenland', with Rijnstrangen/Lingewaarden as a central part of the plan. This plan consists of a new 'river' (i.e. an embanked floodway) along a former channel of the Rhine between the German - Dutch border and the Pannerdensch Kanaal (Rijnstrangen). The second section of the new river is along the river Linge, starting at Doornenburg on the Pannerdensch Kanaal and ending at Druten on the River Waal. The present research aims at investigating the effects of such a new river branch on water levels and the discharge distribution in the Dutch Rhine branches.

1D-Model

We applied a one-dimensional model of the Dutch Rhine branches, the so-called 'Rijntakken-model'. The new rivers Rijnstrangen and Lingewaarden were included with several cross-sections. The bed level of the cross-sections follows the bed level in the area. The shapes of the various cross-sections in Rijnstrangen and Lingewaarden were derived from sketches made by Bureau Stroming. At the beginning of each section a weir is present with a crest level equal to the floodplain level. As boundary conditions, the current design discharge at the upstream end (16000 m^3/s) and Q-h relationships at the downstream ends have been imposed.

Results

A key result is that the discharge distribution at Pannerdensche Kop can be regulated within a large range. It is possible to divert more water towards the south (i.e. the River Waal), but also to the north (i.e. Neder-Rijn/IJssel), depending on the weir levels in the Rijnstrangen and Lingewaarden (Fig. 1). Besides, the new river decreases the water level in various parts of the Rhine branches. Figure 2 shows that effect on the water levels can be up to 60 cm. This drop contributes to the aim of the project 'Ruimte voor de Rivier'.

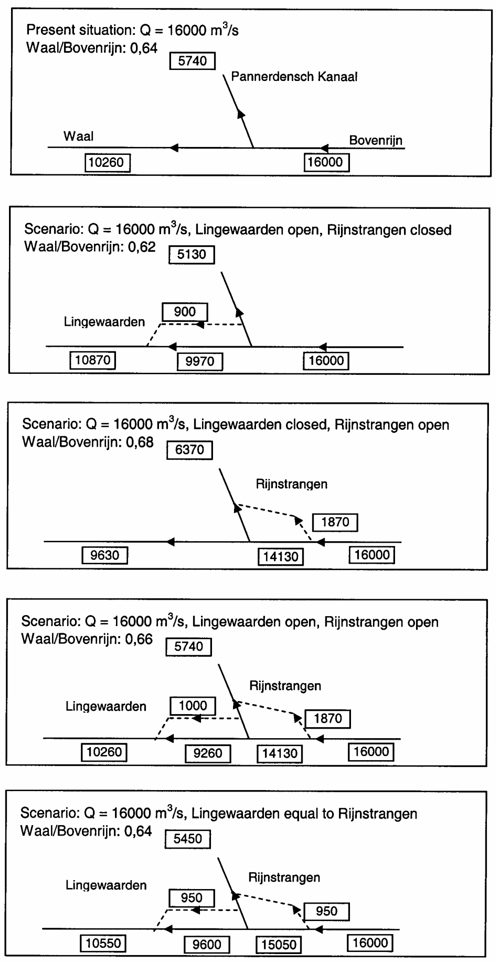

Figure 1. Effect on the discharge distribution in the Rhine branches. The numbers in the boxes refer to the new discharge in each section.

Conclusions and outlook

Including the new rivers Rijnstrangen and Lingewaarden results in:

- a regulation possibility to divert more water towards the northern (i.e. the IJssel and Neder-Rijn) or the southern branches (i.e. the Waal);
- a significant lowering of the water levels.

Effects on the morphology will be subject of further research

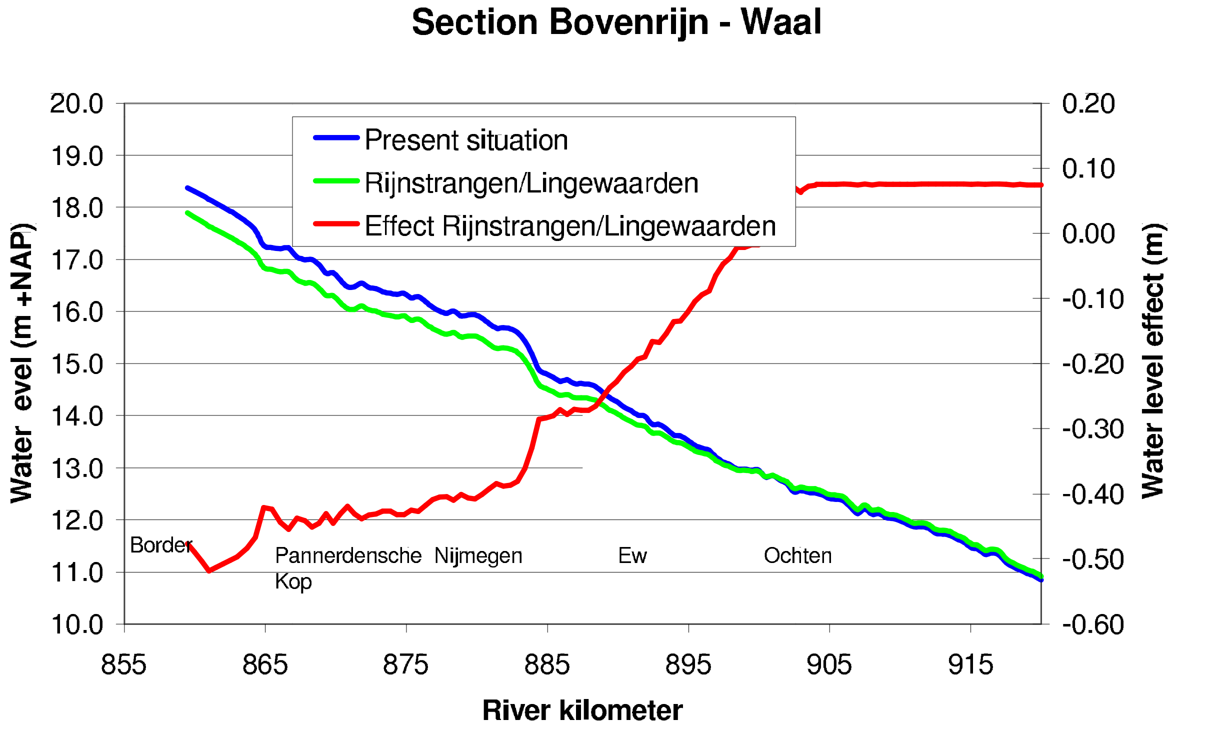

Figure 2. Water level and effect on the water level at a discharge at Lobith of 16.000 m3/s for the present situation and the situation with Rijnstrangen/Lingewaarden. A negative water-level effect means a decrease in water level caused Rijnstrangen/Lingewaarden

Optimal design of multifunctional flood defences in urbanized areas

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Abstract
Partly due to urbanization in the Rhine-Meuse delta, it is often impossible to adjust the existing dikes and thus alternative solutions are needed. Improving the flood defence is no longer a water management and hydraulic issue only, but it has also become an issue of spatial planning and design. Goal of the planned research is to find a method to design multifunctional flood defences in urban areas. This research will focus on the design of new flood defences in new water management systems that have a surplus value for the spatial structure of city and landscape.

Introduction
Traditionally, multiple use of space is applied in the Dutch wetlands. A dike, for example, was often both a flood defence and a road. A dike can therefore be considered as an axis of urbanism. Most settlements have been founded near rivers because of the transport possibilities and the occurrence of suitable soils for agriculture. Gradually, these early settlements have developed into urban areas. The development of smart water management systems is a characteristic element in the process of urbanization of the Dutch lowlands. These systems play multiple roles in the urban patterns with respect to: flood protection, drainage, military defence, transportation, drinking water supply and recreation.

Partly in response to urbanization, natural river floodplains have been reclaimed and quay walls have been raised. Anticipated increases in flood water levels, due to climate change and sea-level rise (Ministerie van Verkeer en Waterstaat, 2000, p.12) have caused a new challenge in flood defence.
In present urban landscapes it is often complicated to adjust the traditional dikes and there is a need for alternative solutions. Improving flood defence is no longer a water management and hydraulic issue only, but it has also become an issue of spatial planning and design. Various interests have to be taken into account.

Flood protection in urbanized areas
In general, the solution for increased flood water levels is sought in two directions: (1) ‘room for the river’ [e.g. dike relocation or ‘green’ rivers (embanked floodways parallel to present river courses)] and (2) strengthening the current flood defence structures. Whereas the latter approach is the ‘classic’ solution, ‘room for the river’ is an alternative in the Netherlands that is presently investigated. In response to the floods of 1993 and 1995 (Fig. 1) the government has encouraged development of this new approach towards flooding, because it was doubted whether strengthening of the current flood defence would be sufficient on the long term. Within an urban context, strengthening (raising) the existing flood defence is often considered problematic and harmful for the city view. On the other hand, how to apply the ‘room for the river’ approach to urban areas is still a matter of debate. We feel that both directions should be combined in order to obtain an acceptable solution.

Figure 1. Flooding in the city of Roermond, 1995.

Figure 2. Dordrecht: flood defence within the context of a historic city centre.

It should also be recognized that water management systems in urban areas, are multifunctional and flood control is not the only aspect that has to be taken into account. Many other difficulties occur at the urban riverfront such as conflicts between traffic demands, the desire for higher building densities and better livability. It should be stressed also that the current historical city view (e.g. Fig. 2) is a result of a constantly changing relationship between the city and her waterfront. This is due to the changing economic relationships, changing views on the relationship between city and water, and changing opinions about flood defence. We feel that placing the current demand for a new urban flood defence strategy into this perspective, may lead to a useful extrapolation into the future. The challenge is to develop one integral multifunctional solution for the current problems of the urban waterfront.

Planned research

The goal of our research is to find a method to design multifunctional flood defences in urban areas. The research focuses on the design of new flood defences in new water management systems, which have a surplus value for the spatial structure of city and landscape. In the design process the two directions in flood defence, ‘room for the river’ and strengthening of the current flood defence structures will be explored. Solutions may involve new types of urban settlements and building constructions in wetlands. Questions about weighing of the interests, decision-making and organisational aspects will also be addressed in our research. They play in a complex field with various actors, in a government policy context as well as in a private context. An integrated approach will be used, which covers relevant aspects in the fields of flood defence, traffic circulation, aesthetics of the city view, landscape-architecture and livability. Futhermore, probabilistic design and risk analysis will be taken into account.

Current activities

Presently, rivers in the Netherlands and several cities on the Rhine branches and the Meuse are investigated, with the main research questions given below.

- What are the characterizations of the rivers in the Netherlands?
- How were the cities founded and in what way did they develop?
- How did and do they cope with floods?

A broad reference work will be the outcome of the first phase of the research, which will be the starting point of finding a method to design multifunctional flood defences in urban areas. Updates of the results of our research can be found at: www.waterbouw.tudelft.nl/public/stalenberg.

Reference

Ministerie van Verkeer en Waterstaat, 2000. Anders omgaan met water; waterbeleid voor de 21e eeuw. Ministerie van Verkeer en Waterstaat, Den Haag, 70 p.

Communication strategies in river management; research plan for comparison of two cases in the Netherlands

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Introduction

The floods that occurred in the Netherlands in 1993 and 1995 confronted the Dutch government with the consequences of a changing climate and spatial developments in the Rhine and Meuse river basins. Peak discharges of these rivers are expected to increase in the future. The traditional technical protection measure of dike re-enforcement, is no longer considered a sustainable solution. Alternative ways of reducing the discharge peaks are spatial measures like dike relocation or lowering the floodplain or a combination of technical and spatial measures. Since the government started the project 'Room for the river' in 2000, possible measures for the Rhine and the lower Meuse have been studied. Examples are the Overdiepse polder retention basin on the Meuse and the dike relocation at Lent on the Rhine.

In the framework of the European 'Freude am Fluss' project, a research plan has been made for a comparison of the cases Overdiepse polder and Lent concerning the communication strategies of government and inhabitants, with the objective to determine the factors that cause local communities to be pro or against 'Room for the river' plans. In this paper the two cases are briefly described and the outline of the planned research is presented.

Figure 1. The locations of the Overdiepse polder and Lent within the central Netherlands.

Overdiepse polder

The Overdiepse polder (Fig. 1) measures 550 ha in area and has 94 inhabitants and 19 enterprises, mostly farms. Since the government considered the Overdiepse Polder as one of the options for a flood retention basin, the inhabitants organized themselves and took the initiative in preparing a plan. The reason for their active participation was the notion that a pro-active and co-operative attitude would help to clear away the uncertainty concerning their future living circumstances.

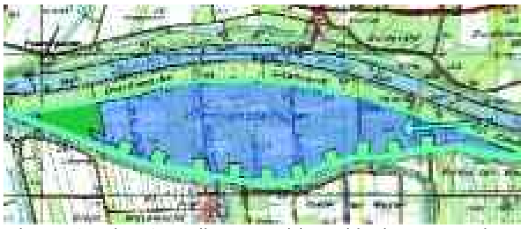

Figure 2. The Overdiepse polder with the 'Terp plan' measures. Area shown 7 km wide; north is up

Various options had been explored of which three plans were elaborated. Finally, in June 2004 government decided that the Overdiepse polder could start with the realization of the so-called 'Terp plan' (Fig. 2). This plan includes a combination of technical solutions and spatial measures, such as dike heightening on the south-side of the polder and the relocation of houses and farms in the polder to elevated locations on the dike. The plan would reduce floodwater levels in the river by approximately 30 cm. The inhabitants are now discussing how to execute the plan and to decide who can stay and who might be relocated outside the polder.

Dike relocation Lent

The Waalkade of Nijmegen and the dike of Lent on the opposite river bank (Fig. 1) form a bottleneck in the Waal River during peak flows, affecting the safety of local communities. Since 2000, the municipality of Nijmegen, the province of Gelderland, the waterboard

Rivierenland and Rijkswaterstaat have co-operated to find a solution for this problem. After an inventory Rijkswaterstaat (part of the Ministry of Transport, Public Works and Water Management) proposed to relocate the dikes near Lent inland (Fig. 3). The inhabitants protested against this plans. Since they had not been involved in the preparation phase and the design of the plan, the inhabitants decided to develop their own plan. With support of experts they prepared the plan 'Lentse Warande' (Fig. 4). In this plan the current dike will be maintained and the floodplain will be excavated. The area between the dike and the Waalsprong, an newly built urban quarter of Nijmegen some 350 m inland, could be developed as a park, partially with temporary buildings. If necessary, this area could provide room for the Waal in the future.

After the presentation of this alternative plan, the municipality of Nijmegen, the province of Gelderland, waterboard Rivierland and Rijkswaterstaat signed an institutional arrangement. They agree with the execution of an Environmental Impact Assessment (EIA) of the two plans and the establishment of a project organisation including: (1) a steering committee, (2) a project group, and (3) a group of representatives of local citizens and their organisations. After the EIA, the steering committee will advice the State Secretary who will decide which plan has to be realized. After this decision the EIA will be published and inhabitants of Lent have a say on the results. If these reactions are judged as relevant, they will be included in the elaboration of the definitive plan.

Research outline

The following steps will be taken in the investigation of the cases described above. The research question is: what are the factors that cause local communities to be pro or against 'room for the river' plans? The first step is to get insight into the perception of each stakeholder of the project, especially concerning the communication between the actors in the project and between the actors and the wider audience. Before conclusions can be drawn about the strategies used, it is necessary to understand the starting-point of each stakeholder and the relationships between the different actors in the project. The second step is the analysis of the project structure and project process itself. The third step is the formulation of theoretical recommendations based on a review of the relevant literature in order to create a framework for the subsequent analysis and comparison of the cases.

The results of these case studies may help to get insight into the key factors of participation and support of local communities in 'Room for the river' plans. The results are expected to reveal underlying motives for stakeholder proposition and opposition. The results will be used for developing a joint planning approach for Freude am Fluss river projects.

Figure 3. Overview of the Lent dike relocation plan. Area shown aproximately 2 km wide; view looking north

Figure 4. Overview of the 'Lentse Warande' plan.Area shown aproximately 2 km wide; view looking north.

Designing institutions for water management

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Abstract
Most water management problems are multi-level and multi-actor problems characterized by a high degree of substantive and strategic uncertainty. For social scientists it is an interesting question which institutions are needed for solving these problems. In this paper it is argued that new practices of network governance (interactive, participatory or open planning processes) are a promising alternative to state power, but that more research is needed on sources of network governance failure. Based on observations made of the room for the river policy process, it is concluded that we are in need of an intelligent combination of strategies of network governance and state power for solving our water management problems.

Introduction
'Institutions matter' is a famous statement by the Nobel prize winner for economics North. Institutions are, in the widest sense, rules. They can either be formal, such as Acts and the Dutch 'House of Thorbecke', or informal, such as the Dutch consensus decision making culture. Anyone who has ever participated in an international research or policy project may have experienced why institutions matter (Meijerink, 1999).

Institutions often show considerable inertia. Nevertheless, some institutions can be purposefully designed (De Bruijn et al., 2002). We may for example decide on the introduction of a market for water services or a 'watertoets' for decision making on land-use policies (Wiering & de Rooij, 2004). In this paper we address the issue of institutional design for solving wicked water management problems.

Wicked water management problems
Most water management problems are wicked problems. Characteristic to these problems are that multiple governmental and non-governmental parties at multiple levels of government are involved in problem solving. These parties generally have different problem perceptions and policy preferences. Moreover, resources needed for problem solving, such as legal, financial and political resources, are distributed amongst them. Finally, wicked policy problems are characterized by uncertainty (Koppenjan & Klijn, 2004). The 'Room for the River' issue, for example, is characterized by both substantive (river discharges expected) and strategic uncertainty (e.g. about strategic behavior of regional and local parties).

Markets, hierarchies and networks for water management
It is useful to think about the institutions needed for solving such wicked water management problems. Basically we can draw on three types of institutions: markets, hierarchies and networks (Thompson et al., 1991). Markets are very good at providing private goods. We might think about possibilities for organizing a market for drinking water supply, sewerage and/or waste water treatment, though we should be extremely careful with that, and it is necessary to protect public values, such as water quality or equal access to water services. For the provision of public goods, such as dikes, or common goods, such as clean water resources, there is a serious risk of *market failure*. In these cases markets do either produce negative externalities, such as water use or pollution to the detriment of others, or free riders, i.e. parties that do not pay for a good or service, but nevertheless enjoy its benefits.

Because of these market failures government plays an active role in water resources management in most countries. In the past decades, however, the water sector has experienced that state power or hierarchy is not very successful in solving wicked problems either. Stakeholders that feel they are worse off with newly developed policies as compared to the status quo often try to frustrate policy implementation successfully. Hierarchy invokes strategic behavior, and in policy controversies scientific research is often used strategically. Rather than a disinterested search for truth, the policy process, then, is characterized by partisan use of research results and reports. The river dike strengthening controversy of the eighties is a clear example of such a 'dialogue of the deaf'

(Sabatier & Jenkins-Smith, 1993), and therefore of *government failure*.

For these wicked policy problems network governance (or interactive decision making) is a promising alternative, mainly as it aims at conditioning a joint learning process. We may distinguish between processes of substantive, strategic and institutional learning (Koppenjan & Klijn, 2004). Substantive learning is learning about cause-effect relationships, policy alternatives and impacts of these alternatives. Strategic learning refers to learning about the perceptions and preferences of others, and the need to take into account these other parties' perspectives by developing more cooperative strategies. Finally, institutional learning refers to the development of shared norms and expectations, and the development of a culture of trust. The processes of deliberation and negotiation aimed at the preparation of a regional advice in the Dutch Room for the Rivers project are an interesting example of such learning. The parties involved learned about the many policy alternatives, the many possible combinations and their impacts. They, however, also learned about possibilities to combine different policy objectives in multi-purpose plans, and by that to address different problems at the same time. In spite of these substantive and strategic learning processes, the relationship between some parties remained rather tense, and a culture of trust has hardly developed. Among other things, this may be explained by the rather coercive strategies the Dutch national government has used in the controversy over the designation of emergency flooding areas (Meijerink, 2004).

Network governance failure

As more experiences have been gained with the new practices of network management now, policy scientists have begun to address the sources of *network management failure*. In spite of the rather positive observations made of the Room for the Rivers policy process so far, it should also be noted that there has been a permanent risk that problems and costs are passed on to other parties or levels of government. This particularly concerns parties' willingness to take policy measures for the benefit of areas and parties situated more downstream. Moreover, not in all cases it will be possible to reach a consensus or negotiated agreement. In the end, we may well need state power to solve these dilemmas of network governance.

Hierarchy or state power should neither be used to simply impose policies nor should interactive policy making be used to create public support for policies that already have been decided upon. Hierarchy, however, may be used fruitfully to create a sense of urgency, which implies that deliberations and negotiations take place within the 'shadow of hierarchy': if parties will not be able to reach an agreement, central government will have to take a decision in the end. Finally, state power may be used to impose conditions that safeguard coordination at higher levels of scale. The safety objectives for the Dutch rivers imposed by the Dutch national government are a good example of that.

Conclusions

Whilst policy scientists have given ample attention to sources of market failure and government failure since long, they have only just begun to address sources of network governance failure. From recent experiences with network governance in Dutch river management we may learn that strategies of network governance have been rather successful so far, but that there are some dilemmas of network governance as well, and that we may well need state power to solve these dilemmas.

References

De Bruijn, H., E. ten Heuvelhof & R. in 't Veld, 2002. Procesmanagement, over procesontwerp en besluitvorming, Academic Service, Schoonhoven.

Koppenjan, J. & E.H. Klijn, 2004. Managing uncertainties in networks. Routledge, London.

Meijerink, S.V., 1999. Conflict and cooperation on the Scheldt river basin. Kluwer, Dordrecht.

Meijerink, S.V., 2004. Rivierbeheer als leerproces, een tussentijdse evaluatie van de PKB Ruimte voor de Rivier. Bestuurswetenschappen 5, pp. 406-427.

Sabatier, P.A. & H.C. Jenkins-Smith (eds.), 1993. Policy change and learning, an advocacy coalition approach. Westview, Boulder.

Thompson, G., J. Frances, R. Levacic & J. Mitchell (eds.), 1991. Markets, hierarchies & networks, the coordination of social life. Sage, London.

Wiering, M.A. & P.A.E. de Rooij, 2004. De watertoets: nieuwe spelregels voor water en ruimte. Bestuurswetenschappen 5, pp. 391-405.

What's on a decision maker's mind? - Identifying barriers in information flows between actors in integrated water management using mental model mapping

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Abstract
This research studies the relation between mental models and the decision process outcome, in the specific case of the Zwolle storm surge barrier. Differences in mental models between stakeholders will result in different lines of argumentation leading to different solution alternatives. The final outcome is considered sub-optimal from a purely technical scientific point of view.

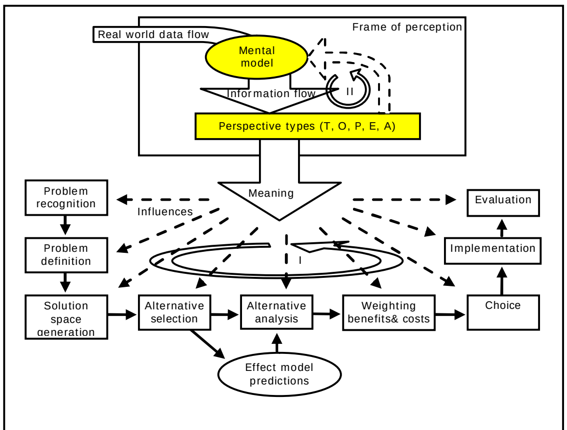

Figure 1. Framework of analysis (Kolkman et al., 2004).

Introduction
A mental model (Doyle & Ford, 1998) contains the elements and relations a stakeholder considers relevant for his position in the decision making process. A mental model restricts information flows to only those aspects that affect him. Restrictions may be on the scale (geographical boundaries, time horizon, level of detail) and on the processes and relations considered relevant (including physical, biological, legal, financial, social). The mental model represents a causal chain of argumentation that starts from the original problem and contains selected data and interpretation thereof, to present convincing evidence for a favoured solution. The mental model can be 'run' to simulate the effects of intended actions. Different stakeholders may use the same starting point and the same data, but with different interpretations, to arrive at different effects.

These effects are subsequently evaluated in the frame against five major perspectives (Courtney, 2001). Perspectives determine what stakeholders see as their interests. Perspectives differ between stakeholders, influence every step of the decision making cycle, and will result in the creation or support of different alternative solutions. The perspectives are related to a stakeholder's (professional, institutional and personal) position in the decision making process, and are indicated with the letters T, O, P, E, A..

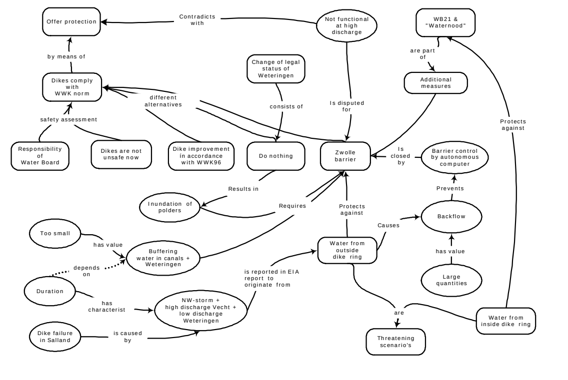

Figure 2. Selected part of the mental map of a T-type actor. Ovals represent elements disputed by one or more other stakeholders.

- T: Technical - A functional and rational orientation with regard to system behaviour.
- O: Organizational - A manager's interpretive orientation with regard to institutional and legal responsibilities and consequences.
- P: Personal - A political and individual orientation with regard to position and power.
- E: Ethical - A moral orientation with regard to codes of conduct and values (e.g. environment).
- A: Aesthetic - An orientation on the beauty and harmony of a design.

Feedback from the frame influences the mental model (loop II in Fig.1). This is an iterative learning process that occurs continuously during the decision making process. Decision disputes are resistant to resolution by appeal to facts or reasoned argumentation present within the mental model because stakeholders' conflicting frames determine what counts as a fact and what arguments are taken to be relevant and compelling. A mental model's general structure can be explained by a stakeholder's dominant perspective. We expect to find categories of mental models that differ between types of stakeholders. Each category has its preferred typical alternative solution. The actual outcome of the decision making process, however, cannot be predicted from the mental models.

Results and discussion

While all actors generally start from the same understanding of the system, some crucial details differ between (groups of) actors. These details concern assumptions and uncertainties present in model calculations [MHWs (Design high water levels), frequencies and inundation severity], and the exact nature of historical data (on flooding of polders). Interpretations of data exhibit much more variation, e.g. on the questions below.

- Does the WWK'96 inevitably prescribe a closed dike ring?
- Can innovating concepts like a risk approach and norm differentiation be applied to dike ring 53?

	Disputed element	Observations from interviews	Scores	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	Dike ring principle	Must be physically closed ...vs... can have an open discharge canal on condition that the safety norm remains guaranteed.	Closed (G), Open (O)	G	O	G	G	G	G	O	G			G, O	G	G	(G)
16	Province WWK approval	Province must dissociate and limit to assessing the reasonability of the EIA report contents ...vs... can fully participate on contents aspects also from the start of the project	Distance (R), Involvement (M)	R	M	R	(M)	M	R		R *	R		M		R	
33	Water system discharge peaks	Discharge peaks from the river Vecht and the Sallandse Weteringen do not coincide ...vs... in the past the discharge peaks were always observed to coincide	Differ (N), Coincide (S)		S		-	S	N	S		N	S	-*			S

Figure 3. Example rows of the analysis overview grid, showing relevant generalized disputed concepts with stakeholder scores. The scores can be related to a stakeholders' dominant frame perspective. The stakeholders interviewed are listed across the header of the table with a code number (1-14).

Materials and method

The theoretical framework is applied to the Zwolle storm surge barrier case. The case concerns the improvement of sections 1 and 2 of dike ring 53, as required by the act 'Wet op de Waterkering 1996' (WWK'96). The researcher was bootstrapped using the EIA (Environmental Impact Assessment) project and related documents, and preliminary talks with selected stakeholders. Mental models and frame elements were elicited from 14 stakeholders using semi-structured interviews (Kolkman & Van der Veen, 2004). Interviews were processed into mental maps (Fig. 2). A total of 67 disputed map elements were analysed in an overview grid (Fig. 3). The main map elements were processed into a causal decision explanation model (Fig. 4).

- How is the distribution of institutional responsibilities and accompanying expertise between Water Board, Province and Ministry to be interpreted?
- Can the city centre of Zwolle be flooded by water from the river Vecht?
- Is the city centre of Zwolle safe for flooding when the storm surge barrier is closed?

Mental models of some actors show elements of careful construction toward a desired outcome, or are reconstructed at a later time to legitimise the outcome and to accommodate new events. Remarkably none of the actors supports the original dike improvement plan.

Conclusion

The T-perspective apparently has 'lost' the argumentation 'battle' against the O-perspective. The P- and E-perspectives explain the project delay. The resulting approach to separate water protection and water control does not solve the flooding problems in Salland, upstream of the Zwolle barrier. The case results confirm the theoretical framework. Different stakeholder perspectives can be related to different (groups of) mental model elements. An overview grid is suitable to analyse disputed concepts. The mental models reveal assumptions and interpretations implicitly present in the various alternative solutions, identify barriers in communication and information flow, and can be used to explain the decision process outcome.

References

Courtney, J. F., 2001. Decision making and knowledge management in inquiring organizations: toward a new decision-making paradigm for DSS. Journal of Decision Support Systems 31, pp. 17–38.

Doyle, J. K. & D. N. Ford, 1998. Mental models concepts for system dynamics research. System Dynamics Review 14(1), pp. 3-30.

Kolkman, M. J., M. Kok, A. van der Veen, 2004. Concept mapping as a new tool to visualise the use of information in decision-making. Physics and Chemistry of the Earth 30 (4-5), pp. 317-332.

Kolkman, M. J. & A. van der Veen, 2004. Mental models - the root of precautionary approach? Civil Engineering and Management research reports, 2004R-008 / WEM-011 (Int. r. no. 1568-4652). Civiele techniek (Faculteit CTW), Universiteit Twente, Enschede, 29 p. (abstract available at http://upem.er.dtu.dk/programme.htm)

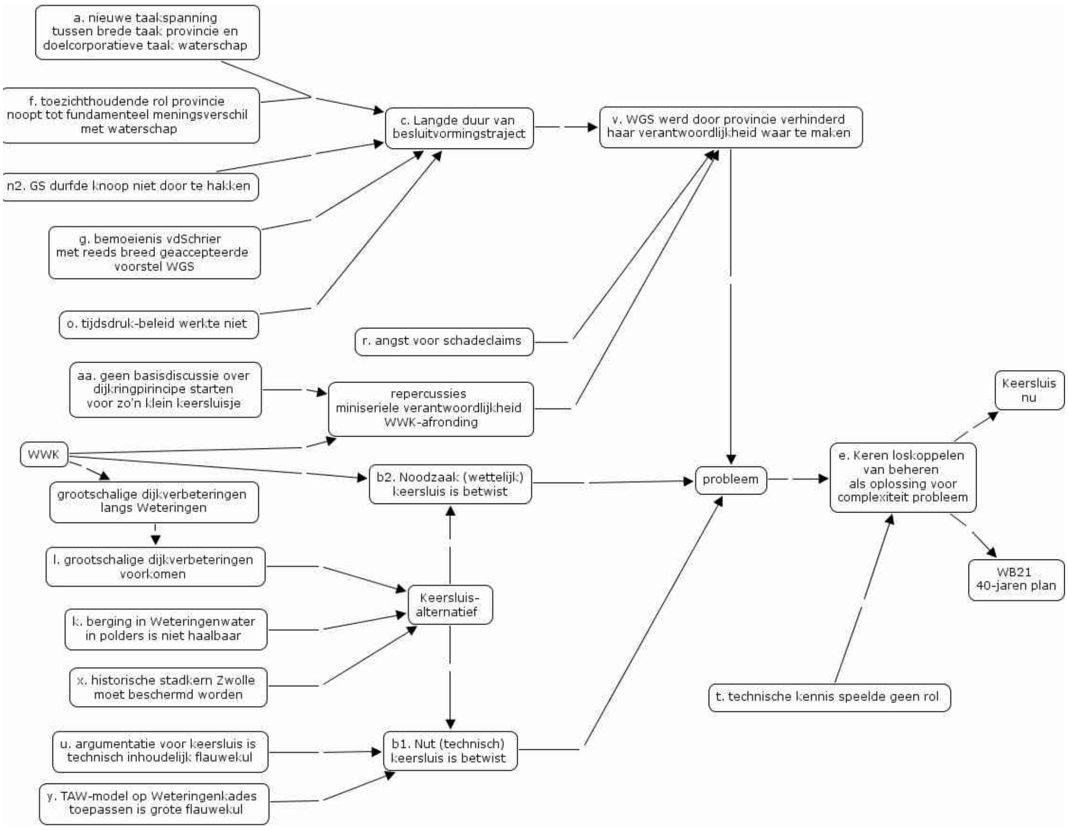

Figure 4. Top part of causal decision explanation model

Planning a green river as a solution to increasing discharge in an urbanizing area on the River Rhine

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Introduction

Future land management in the upper part of the Rhine delta, The Netherlands, will face two problems in the near future. The urban fringes of the two medium-sized cities of Arnhem and Nijmegen will expand strongly, and urban sprawl may be a threat to the quality of the environment. At the same time, more space is needed for the safe discharge of river floods, which are expected to increase in the near future due to climatic change. Since the River Rhine floods of 1993 and 1995, this is a political issue of high urgency.

We investigated whether a new, large river by-pass, called floodway in the USA or green river in The Netherlands, will provide a solution to both problems mentioned (Wolfert et al., 2004). Our example was the Mississippi delta, where the Morganza and the Bonnet Carre floodways were constructed following the Great Flood of 1927 to pass floodwaters from the Mississippi River to the Gulf of Mexico, thus safeguarding the city of New Orleans from flooding.

The planning of such a green river in a cultural landscape will involve major land use changes and many people will be involved in the decision making. Therefore, aims of the study were: (1) to indicate possibilities for new types of land use and to visualize the future landscape and (2) to demonstrate the impact on the water levels in the river system during flood events. The results were compared with the effects of retention polders in the same area, which is another option of which examples exist along the Upper Rhine in Germany.

Plan design

The Green River Lingewaarden comprises two reaches (Fig. 1). The upstream Rijnstrangen reach is surrounded by old dikes as these 3200 ha of land were regularly flooded until the 1960s. The downstream, new Lingewaarden reach is planned in the former floodbasin in between two embanked Rhine distributaries, the Rivers Waal and Neder-Rijn. In the lowest part of this floodbasin, 2900 ha of green river is designed with a minimum width of 500 m near important highway and railway crossings in order to reduce construction costs, but much wider where there are no built-up areas at present or envisaged in the very near future, in order to allow some backswamp restoration in this area.

Figure 1. The green river, planned along the present Rhine distributaries (present embanked floodplain in blue). Area shows measures ~45 km in width; north is up.

For each of the two options water levels and dikes heights required were calculated. Water depth was calculated using data on present water levels – assuming the green river will prevent maximum water levels to rise – and data on altitude. In case a green river is preferred, new dikes have to be up to 8 m high, while a choice for the option of retention basin requires dikes of more than 10 m high. As a green river, the area will discharge water as soon as the present embanked floodplains are flooded and thus will function approximately once in one or two years as a floodway. As a retention basin part of the discharge of extreme floods events is stored in the area, and released as soon as the water levels in the river system get lower, an event which is estimated to occur only once in approximately 600 years.

Future landscapes

Future land use was explored based on the qualities of the present landscape, spatial developments in land use, and future flooding frequencies and water levels. It was assumed that the frequent presence of water in a green river will induce land use changes, but that the rare inundation of a retention basin will not lead to changes. Thus, the option of a green river will enhance functions such as nature and recreation. The frequent presence of water may attract building high-quality residences along the new dikes. The new dikes may be used for new types of recreation infrastructure such as long distance footh pats and cycle tracks, that enable citizens to enjoy their surroundings more than before.

Based upon the local qualities of various parts of the area, new land use combinations were described to occur in the various parts of the green river (Fig. 2). In the Rijnstrangen reach emphasis will be on agriculture with nature, in the eastern part of the Lingewaarden reach development plans with urban parks may be anticipated (Fig. 3, see page 19), while in the western part of the Lingewaarden reach continuation of agricultural use will conserve the highly esteemed openness of the present landscape.

Figure 2. New land-use combinations in the various parts of the green river

River management

When the so-called design discharge will increase from its present 16.000 m^3/s to a future 18.000 m^3/s, the new green river will discharge 2000-3000 m^3/s, which will lead to a drop in water levels of approximately 60-100 cm along the present dikes. In the case of a green river, there is no impact on water levels in the downstream river reaches in the delta, as would be the case when retention polders were constructed. However, that option would only lead to a 35-40 cm drop in water levels in the study area, which is not sufficient in the long run. The new design discharge would require a retention basin of 8-10 times the size of the area investigated here.

The construction of a green river does not change the discharge distribution over the various Rhine distributaries profoundly, but more research is needed on this. An advantage of the option of a green river is that it does not require any operational management during the rise of the water levels. In contrast, a retention basin must be opened and closed with precision on the right moment, otherwise it will not effectively reduce the flood peak water level in the river system. The decision on whether to open the basin or not are seen as a great risk of failure.

Conclusions

Compared to the option of retention basin, construction of a green river will be the best in order to stop the present process of urban sprawl, because of the frequent inundations. These inundations will also induce new types of land use contributing to the environmental quality of the urban areas, and will enhance development plans with high-quality residences. Realization of the latter may contribute to the financing of the construction of new dikes. Besides we argued that a green river is not only a sufficient but also a robust solution to the increasing river discharges, as it relies on natural functioning without management procedures, resulting in a much lower risk of failure during floods.
We concluded that a green river is a rigorous solution, but deserves the attention of decision makers, because it provides long-lasting opportunities for an environment which is safe and pleasant to live in.

Reference

Wolfert, H.P., L.C.P.M. Stuyt, A.G.M. Hermans, J. Kruit, R.J.W. Olde Loohuis & F. Klijn, 2004. Bergende stroming KAN. Alterra-rapport 973, Alterra, Wageningen, 23 p.

Figure 3. The future landscape in the urban part of the Lingewaarden reach

Rapid assessment methodology for river management with application to the Lower Meuse - proposed research

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Introduction

Recent peak discharges in several large European rivers, such as the rivers Meuse (Fig. 1), Rhine, and the German Elbe River led to the awareness that flood safety is still a key aspect in strategic river management. However, this aspect is sometimes conflicting with other functions, such as spatial planning, ecology and agriculture. Trade-offs have to be made between the various objectives. This project aims at improving strategic river planning by providing a flexible and integrated framework for river management.

Figure 1. Peak discharge in the Meuse, Geulle 2003.

Problem identification

Various tools apply to make the required trade-off in river management (Nieuwkamer, 1995; Schielen et al., 2001; Matthies et al., 2003; Ministerie van Verkeer en Waterstaat, Rijkswaterstaat Directie Limburg, 2003). Decision support systems, different models and qualitative studies can be used to assess river strategies in an integrated way. Although considerable research effort has been spent on the development of integrated tools the practical applicability often remains limited due to a number of reasons: (1) the occurrence of blank spots where no measures were or could be assessed; (2) a lack of flexibility to cope with changing future conditions or end-user requirements; (3) difficulties with integration of qualitative and quantitative model concepts.

Integrated water management requires a method that allows for quick iteration in case of changing conditions either in the field of climatologic change or policy or end-user requirements. Furthermore, to cope with blank spots, the method should be based on minimal data requirements and relatively simple calculations. Finally, qualitative and quantitative model aspects should be integrated. The ongoing Integrated Exploration Meuse (Fig. 2), one of the largest river planning projects in the Netherlands, serves as a case study for this research.

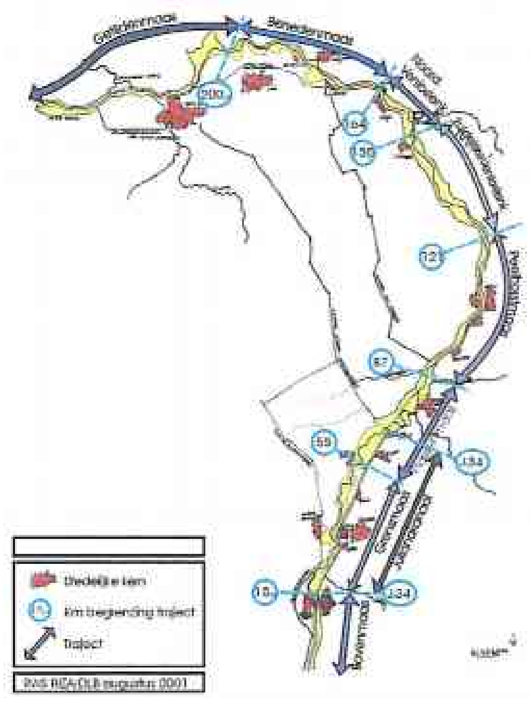

Figure 2. Lower Meuse; study area for IEM (Ministerie van Verkeer en Waterstaat, Rijkswaterstaat Directie Limburg, 2003).

Research methodology

The research comprises the following steps.

- Qualitative systems analysis: consulting end-users, stakeholders and selected experts to make an inventory of relevant indicators, measures, and scenarios for future conditions. Modeling effects:

collecting data and theoretical concepts to model to describe the relations in the qualitative systems network. The availability of the Planning Kit Meuse, developed by WL Delft and involving the hydraulic effects of measures, allows for calibration of results.
- Evaluation of river strategies: testing robustness of river strategies formulated for the program Integrated Exploration Meuse (IEM) under the formulated scenarios and ranking the strategies.
- Verification of the methodology: testing the generic applicability of the method by means of a second case study.

Integration of qualitative and quantitative aspects takes place by using fuzzy set theory. This approach originates from social science and will allow for integration of qualitative knowledge in the model, resulting in a generically applicable approach (Fig. 3).

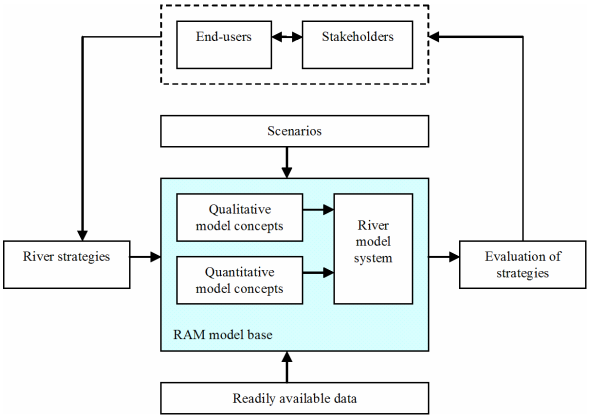

Figure 3. Application of the RAM approach.

Acknowledgements
This project is partially embedded in the Institute for Governance Studies of the University of Twente. Results of the IVM Study and the Planning Kit Meuse, developed by WL | Delft Hydraulics, will be used.

References
Matthies, M., J. Berlekamp, S. Lautenbach, N. Graf, S. Reimer, B. Hahn, G. Engelen, M. van der Meulen, J.-L. de Kok, K.U. van der Wal, H. Holzhauer, Y. Huang, M. Nijeboer & S. Boer, 2003. Pilotphase für den Aufbau eines Enstcheidungsunterstützungssystem (DSS) zum Flusseinzugsgebietsmanage-ment am Beispiel der Elbe. Bundesanstalt für Gewässerkunde, Projektgruppe Elbe Ökologie, BMBF Forschungsvorhaben FKZ 339542A, Koblenz-Berlin, 102 p.

Ministerie van Verkeer en Waterstaat, Rijkswaterstaat Directie Limburg, 2003. Integrale verkenning Maas; advies, hoofdrapport en achtergronddocumenten. Ministerie van Verkeer en Waterstaat, Rijkswaterstaat Directie Limburg, Maastricht.

Nieuwkamer, R.L.J., 1995. Decision support for river management, Ph.D. thesis, University of Twente, Enschede.

Schielen, R.M.J., C.A. Bons, P.J.A. Gijsbers, W.C. Knol, 2001. DSS Large Rivers, Interactive Flood Management and Landscape planning in River Systems: development of a Decision Support System and analysis of retention options along the Lower Rhine river, Final Report IRMA-Sponge-04-WP. NCR-publication 13-2001, Netherlands Centre for River Studies, Delft, 61 p.

Damage due to low flows on the Meuse

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Abstract
In this research the damage due to low discharges on the Meuse has been analysed to get a better view on the scope of the low flow problem. The research area consists of the Dutch and the Flemish part of the Meuse upstream of Roermond and the canals fed by it. A model has been developed to assess the total damage and the distribution over different regions and economic sectors in a number of situations. Total damage varies from a few million Euros in a medium dry year to ten times that much in an extreme dry year. Most of the damage occurs in the navigation sector and the power generation sector. Climatological and economical development will increase future damage substantially. On the other hand, much can be gained by applying appropriate management strategies.

Introduction
The main aim of this research is to create insight into the damage due to low discharges of the Meuse (Fig. 1). This insight can help water managers (e.g. Rijkswaterstaat) to evaluate international, national and regional agreements concerning the distribution of low flows. It can also give direction in the development of strategies to alleviate the low flow problem now and in the future. The research area consists of the Dutch and the Flemish part of the Meuse upstream of Roermond and the canals fed by it (like the Albert Canal, Juliana Canal and Zuid-Willemsvaart).

Figure 1. Low flows on the Meuse in 2003

Damage model
A model has been developed to assess the total damage and the distribution of the damage over several regions and economic sectors in a number of situations. The model calculates the damage that would occur in the current system, if it would be confronted with certain characteristic discharge series, in three steps. First, the distribution of the discharge over the main branches of the water system is determined. Then water shortages are quantified for each economic sector, by comparison of water supply and demand. In the last step, the financial damage is assessed for the relevant economic sectors: navigation, agriculture and power generation. Damage to navigation and agriculture is caused by water shortages, but damage to power generation is caused by high temperatures of the river water, which is used for cooling purposes.

Results
The damage that can be expected in the current situation has been computed for a number of characteristic years, based on the yearly cumulative discharge deficit. The damage varies from about 6 million Euros in a 50%-dry year to over 30 million Euros in a 1%-dry year (Fig. 2). In a 50%-dry year almost 90% of the damage occurs in the power sector, but in a 1%-dry year that fraction is only about 30%. In a 1%-dry year most of the damage occurs in the navigation sector. The damage is caused by the increasing delay of ships at locks, when more economical lock procedures are applied. The damage to navigation is particularly high on the Albert Canal in Flanders, where – in contrast to in the Netherlands - no pumps are installed to pump back the locking water. In the agricultural sector substantial water shortages do occur, but the damage caused by these shortages is negligible.

To develop insight into the possible future increase of damage, the model has been applied to a number of scenarios for climatological and economical development. In the most extreme of the two applied climate change scenarios, the damage in a 10%-dry year nearly doubles in 100 years time. A substantial part of the extra damage is caused by an increase in the water temperature. The scenario for economical development predicts an increase in damage of about 20% in 10 years time. The increase in damage is mainly caused by an increased intensity of ships on the Juliana Canal and the Lateral Canal. If the economical growth will continue with the same rate, the increase in water demand will add more to the low flow problem then the decrease of the water availability due to climate change.

Finally, the model has been used to identify beneficial solutions to the low flow problem, by assessing the damage that occurs under several management strategies. The damage to power generation is not taken into consideration in the evaluation of management strategies, because the strategies do not influence the water temperature. Since the damage to agriculture is already very limited, the strategies are mainly aimed at decreasing the damage to navigation.

The appropriate management strategies lead to a decrease of the total damage of nearly 20% to over 50% in a 10%-dry year. First of all, much can be gained by adjustment of the water distribution over the economic sectors and the regions in the research area. To decrease total damage, more water should be made available for navigation at the Juliana Canal and the Albert Canal. The distribution of water over the river system can however not be adjusted without (political) effort. Beside operational measures, a couple of appropriate strategical measures can be identified, among which the installation of pumps to pump back the locking water.

Discussion

The possible fault in the calculated damage is caused by various sources. First of all, a few economical sectors and processes are excluded from the model. Secondly, the model schematisation is a little inaccurate due to the fixed discharge distribution and the simplified damage functions. Finally, the uncertainty in the input and the model parameters – mainly the parameters for the power generation and navigation sector - cause quite some uncertainty in the output. Therefore, the total uncertainty in the calculated damage is substantial.

Conclusions and recommendations

Low flows on the Meuse are mainly a problem to navigation and power generation. Part of the damage is unavoidable and has to be accepted. Nonetheless, the total yearly damage can be decreased substantially by applying appropriate management strategies. Especially with regard to the expected increase of the low flow problem due to climate change and economical development, it seems to be wise to implement a combination of operational and strategical measurses. To establish a widely accepted package of effective and efficient measures, it is recommended to consider all financial and non-financial effects to the interested parties.

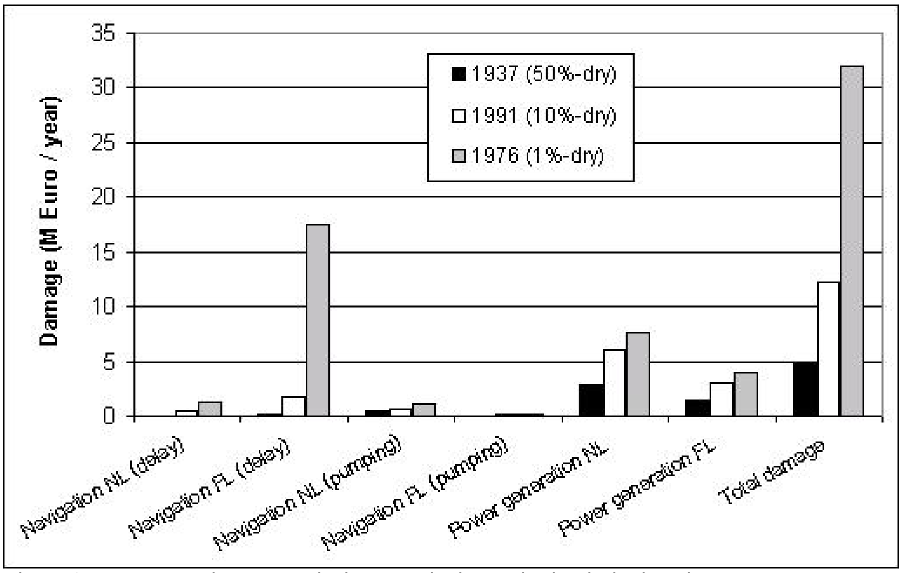

Figure 2. Damage to the economical sectors in the Netherlands (NL) and Flanders (FL) in characteristic years.

Integrated flood-damage and risk assessment

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Introduction

Flood losses used to be assessed statistically, based on the risk analysis approach (CUR, 1990; Vrijling, 2001). With the development of remote sense technology and driven by the rapid climate change, the physical-based approach becomes more frequently applied (Van de Sande et al., 2003). Both approaches appear important in decision making: the former in long-term flood defense planning and the latter in short-term flood mitigation management.

The study of natural systems calls for an integrated approach in risk assessment. In Europe, shifted from structural measures to non-structural measures, modern flood risk management has moved towards improving flood mitigation through the improvement of flood warning and modelling systems (Penning-Rowsell et al., 1994). However, in densely populated river basins in countries such as China, structureal measures remain important (Yin et al., 2001). Thus, risk assessment is required to be able to analyze the possible outcomes of *any* plan, strategy or project, at *different* temporal and spatial scales. In this study, attention shall be paid to the issues mentioned below.

Figure 1. Flood damage caused by high flow velocity (from BBC 2004: http://news.bbc.co.uk/1/hi/in_pictures/3571748.stm).

- Most of the damage functions were depth-based. Improvement is needed due to the neglect of quantified inclusion of important variables such as velocity (Kelman, 2004; Fig. 1).
- Previous uncertainty analysis of flood risk assessment focuses on internal parameters involved in the risk model (e.g. NRC, 2000). External uncertainty such as uncertainty propagation through hydraulic models is rarely reported.

Methodology and case study

Key components and processes of the integrated flood damage and risk assessment system are shown in Figure 2. A case study has been set up on the river reach near Sandau in the River Elbe in Germany. Monte Carlo simulation propagates uncertainty through the system. The dike effect is studied with an artificial dike break simulated with SOBEK2D.

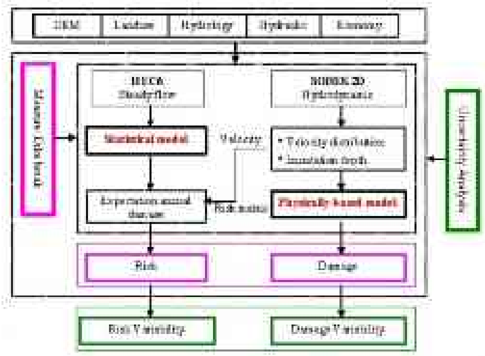

Figure 2. Framework of the integrated flood risk assessment system.

Results

The system can assess flood risk with: (1) expected annual damage; (2) damage associated with a certain flood event; (3) the impact of flood mitigation measures. Here, two typical results are presented.

1. A risk-level map (Fig. 3) – This map has been obtained by combining the maps of percentage damage and the velocity distribution. The idea is to distinguish four risk levels indicated by the indexes of R1 to R4, which are corresponding to activities to be taken for decision making. The levels of risk can be different nationwide.
2. The dike-break-effect (Fig. 4) – This effect was assessed using Monte Carlo simulation of the event-based damage

model. The result shows that damage is always higher when dike break occurs. However, this result only shows the local impact. Non-local impacts can be obtained by enlarging the modelling area downstream towards the area of interest. This work is still in progress.

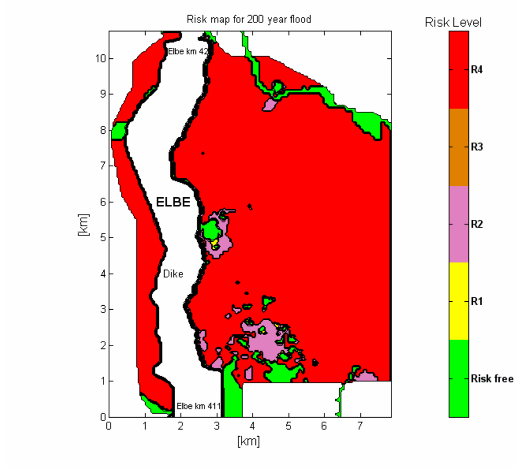

Figure 3. Risk-level map

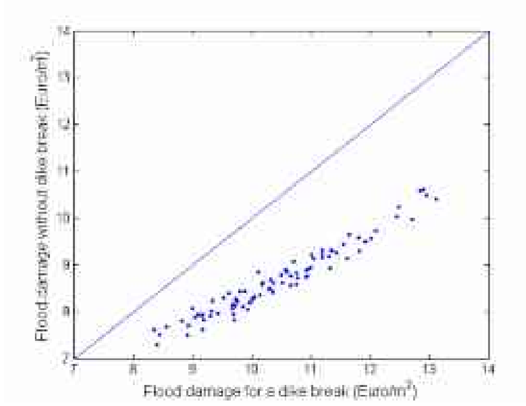

Figure 4. The dike-break-effect

Conclusions

- An integrated flood risk assessment system has been developed. It can be used to provide multi-dimensional aids to flood management decision making in long-term planning and short-term operations of the flood defence system.
- Inclusion of velocity improves the damage-driven forces.
- Integrated uncertainty analysis assists flood risk presentation with more comprehensive information.

Acknowledgements

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References

CUR/TAW, 1990. Probabilistic design of flood defences, Central for Civil Engineering Research and Codes, report 141, Gouda.

Kelman, I. & R. Spence, 2004. An overview of flood actions on buildings. Engineering Geology 73, pp. 297-309.

NRC, 2000. Risk analysis and uncertainty in flood damage reduction studies. National Academy Press, Washington D.C. (http://www.nap.edu)

Penning-Rowsell, E., & M. Fordham, 1994. Floods across Europe - flood hazard assessment, modelling and management. Middlesex University Press, London.

Van der Sande, C.J., S.M. De Jong, & A.P.J. De Roo, 2003. A segmentation and classification approach of IKONOS-2 imagery for land cover mapping to assist flood risk and flood damage assessment. International journal of Applied Earth Observation and Geoinformation 4, pp. 217-229.

Vrijling J.K., 2001. Probabilistic design of water defense systems in The Netherlands. Reliability Engineering and System Safety 74, pp. 337-344.

Yin, H. & C. Li, 2001. Human impact on floods and flood disaster on the Yangtze River. Geomorphology 41, pp. 105-109.

Baseline MIXER: a GIS application for managing geographic information and hydraulic models for rivers

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Abstract
River engineering in the Netherlands now relies heavily on detailed geographic information. Information ofn dikes, elevation and vegetation is gathered and maintained in an instrument called ‘Baseline’. From this database the required hydraulic, ecologic or morphologic models are drawn. This is done largely automatically. Recently the Baseline data controlling environment was extended with the facility to incorporate changes to the database. This extension is called the MIXER.

What is Baseline?
Baseline is a GIS-oriented database for managing and processing spatial data for 1D, 2D or 3D hydraulic models. It is an automated switch between ground truth data and model input for models such as SOBEK and SIMONA (WAQUA and DELFT3D) models. It provides structures for data managing and applications for editing.

Baseline was developed in ArcInfo, mainly using the Arc Macro Language (AML). Some parts have been programmed in Fortran and C++. The Baseline application requires either ArcInfo 7 or ArcGIS 8, and runs on UNIX, NT or XP platforms. At the moment RIZA is working on a conversion to the ArcGIS programming environment.

Baseline and data
The workflow of Baseline involves three data-levels.

1. Primary data - The Baseline input originates from three types of data sources: depth soundings points en lines with height information, topography and files that describe ecotopes. If necessary, data can be pre-processed before being saved in the Baseline database.
2. Derived data - Baseline software applications process the primary data into derived data like a Digital Elevation Model, Roughness-data, Weirs and Sobek-sections.
3. Applications - Primary and derived data serve as input for hydraulic and morphological models. Baseline contains applications to generate input files for SOBEK, WAQUA and DELFT3D.

Relations with primary and secondary processes
Calibrated WAQUA, DELFT3D and SOBEK models for the river Rhine and the river Meuse have been made with Baseline. The WAQUA models are typically used to assess the design water levels. SOBEK models are regularly used for flood prediction in the lower parts of the Rhine and Meuse. Because all data are managed in Baseline, it is easy to update these models on a yearly basis.

Baseline MIXER
In 2003 the Baseline data controlling environment was extended with the facility to incorporate changes to the database. This extension is called the MIXER. It is used to alter the database conform proposed human interventions or autonomous changes within the prototype. The extension enables the user to include a large number of changes to the data model of the prototype automatically in one simple action.

This addition enables us to make strict distinction between the actual geometry and river management measures. Measures are defined as specific changes of the geometry. Strict distinction between actual situation and measures not only promotes the integrity of the databases itself, it also makes the information of proposed measures transparent and suitable for exchange by means of e-mail. Because the information is entirely geographic it is accessible to anyone that has access to ArcGIS software. It does not require any prior knowledge of hydraulic models.

Baseline and large studies for River management
Baseline is used in a number of large studies for river management, such as Room for River and the river Meuse project. In these projects Baseline proved to be a suitable tool for modelling any change in river geometry. Examples are widening or lowering the main channel, lowering of the floodplains (e.g. Fig. 1), removal of bottlenecks in the river and the

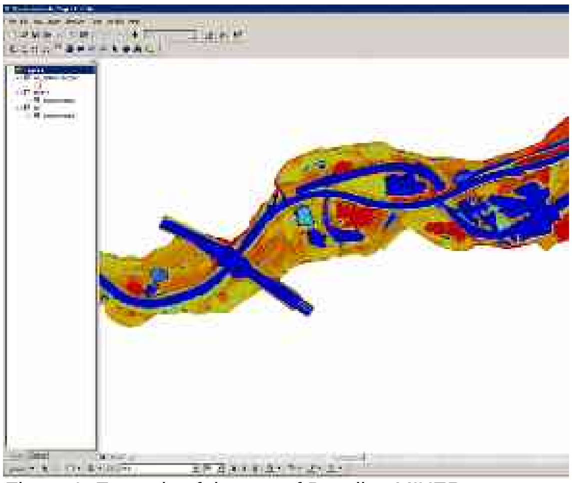
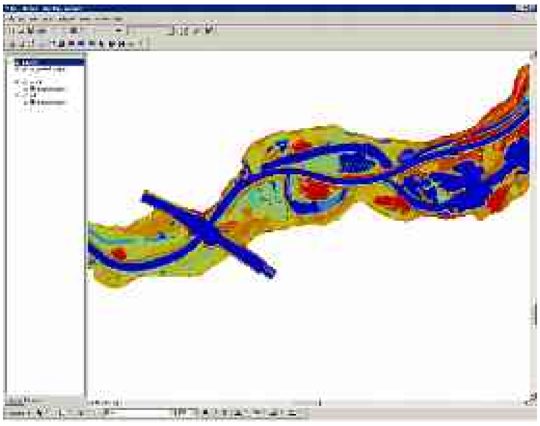


Figure 1. Example of the use of Baseline MIXER.
(a) Elevation Model in actual situation.



(b) Elevation Model after a possible measure

planning of scenic areas. The use of Baseline in such projects is very beneficial because results and hydraulic models are reproducible and objective.

Nowadays, by development of the MIXER, Baseline is an essential tool for hydraulic data management in projects such as 'Maaswerken' and 'Room for the River'. Measures that increase the discharge capacity of the rivers are processed in Baseline, and then converted with the MIXER automatic into the hydraulic models. With these models, the effects of the different measures are assessed.
For instance, when studying the IJsseldelta area in the Netherlands, two plan alternatives were made for the same area. In one of the models the proposed construction of a silt depot in the lake was incorporated, in the other model it was not. In order to be able to make calculations for the current situation and the situation after completion, both models were made and managed by Baseline.

Conclusion

We think the approach of database and MIXER is such a success that it should be extended further. Until now soil composition and features have not been included in the database. These are probably the next two characteristics to be gathered within the database. More challenging are other features like economic value, ecologic value, fauna and navigation intensity. Because the system of database and MIXER is so well fitted for al kinds of geographic network analyses, we think further extension of the databases is probably the best way to fulfill the promises of true integral river management.

River widening: from understanding the subsurface to digging for 'gold'

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Abstract
The subsurface plays an important role in the necessary subsequent steps when dealing with the planning of river widening. It determines, together with design and location, the quality and quantity of the materials that will be removed. Geological, geomorphological, socio-economic and environmental information therefore is, together with risk-assessment, of great interest for planners and decision makers in river-widening projects.

This paper presents the different necessary subsequent steps when dealing with the planning of river widening: starting with a phase of choosing where a preliminary designed project should or may take place, followed by the (sub)surface effects phase (including an EIA - Environmental Impact Assessment) plus an insight in the raw material flows, and a phase of collection of necessary additional new information, eventually leading to the implementation of the river-widening project itself. Knowledge of the subsurface could and probably should play a crucial role, especially in combination with other more superficial data and socio-economic considerations.

Introduction
The subsurface plays an important role in the necessary subsequent steps when dealing with the planning of river widening. Four phases are distinguished within the river-widening process: (1) the investigation of geological information, together with several other important themes, to understand the surface and the subsurface; (2) the creation of an EIA ('MER') describing the (interaction of) surface and subsurface effects of the river-widening processes; (3) the collection of extra information on various subjects; (4) a final phase that leads to implementation of the river-widening project and restoration of the area, often after many years of discussion and deliberation. Below, special emphasis is given to the important role of the subsurface within each phase mentioned.

Phase 1: geological information... understanding the earth
In the first phase (choosing where a preliminary designed project should or may take place) describing and understanding the (sub)surface provides necessary input for the decision making process. A world of information is often available about the subsurface and the surface, mainly from borehole data and various thematic maps. Combined they provide insight in geology, morphology, geotechnology and hydrology. Using 3-dimensional geological modelling, geological interpretation techniques, geostatistics and Geographical Information Systems (GIS) the subsurface can be described and understood (e.g. Fig. 1). In this way the subsurface can provide the necessary input for the decision making process. It can work as a solid underlay for other relevant thematic maps.

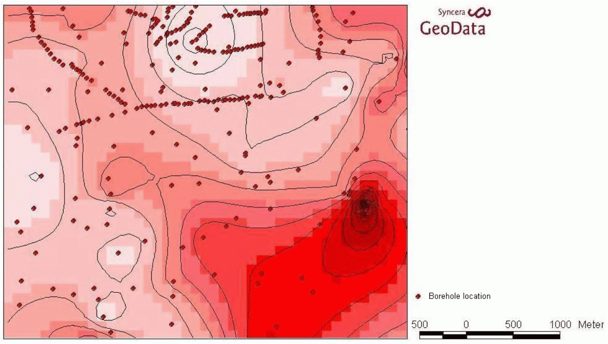

Figure 1. Depth of the top of the coarse sand deposits belonging to the Kreftenheye Formation in the Tiel area along the river Waal.

Phase 2: combining information - effects at the surface
In the next phase subsurface data are combined with other demands regarding river widening. Such as, the preliminary technological project design, flood-control and more superficial data (environmental data, pollution data, socio-economic data, laws and policy, etc). In this way a well-balanced assessment can be made where to undertake river widening.

Many of these items are dealt with in an Environmental Impact Assessment (EIA) or 'MER' in Dutch.
Important items are a careful planning of material flows, combination and clustering of different projects, and dealing with land-use, nature and mineral planning in a smart way. Together with insight in the release of economically interesting raw materials, and sustainable use of re-usable materials these are all important aspects of the assessment and may help making a well-balanced choice.

Phase 3: getting extra information

In this phase a decision about the exact location for the project and the final design will be narrowed down. Getting closer to the phase of implementation it is often considered necessary to collect extra information (e.g. Fig. 2). Information that may influence the choice for the exact location of the new by-passes and dikes. Information that may lead to possible benefits when the removal of polluted soil can be avoided, or that creates possibilities for nature restoration in combination with mineral extraction (e.g. Fig. 3). Well-documented information is especially important as environmental and planning laws are strict. As well as to address nature and environmental groups in a proper way to avoid slowing down unnecessarily the decision-making process.

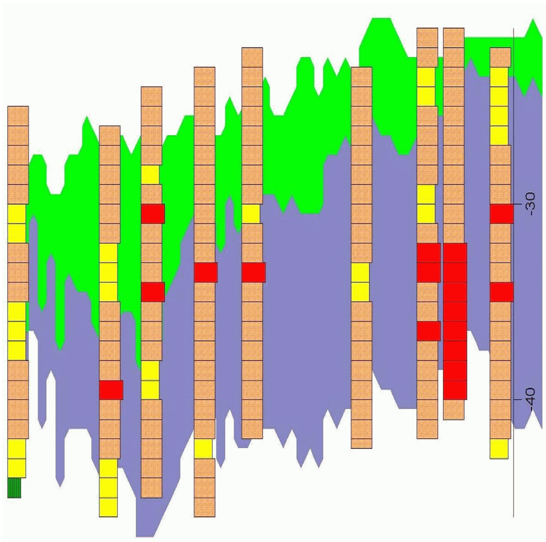

Figure 2. Example of a simple lithostratigraphic profile based on extra borehole data (North Sea).

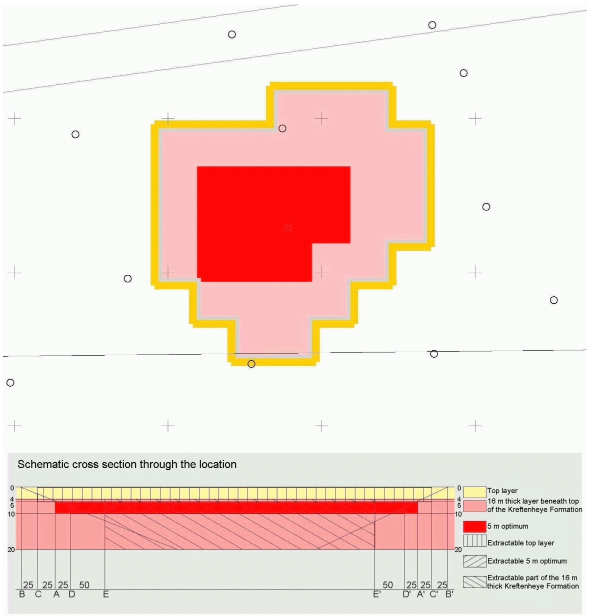

Figure 3. Example of the calculation of the quantity of extractable coarse sand beneath a layer of fine sand (after Rijkswaterstaat, 2004).

Phase 4: digging for 'golden opportunities'

Finally, when the river-widening project will be implemented, often only after many years of deliberation and discussion, well-documented and readily available information will enhance the implementation process. Leading to efficient digging and building, well-balanced material flows and sustainable raw material management. Maybe, together with socio-economical benefits, some financial benefits from economically interesting building materials can be obtained. In this way river widening can be considered 'digging for golden opportunities'.

Reference

Rijkswaterstaat, 2004. Beton- en metselzand uit de Noordzee? Eindrapport van de PIA Subwerkgroep Zeezand; resultaten van de haalbaarheidsstudie naar beton- en metselzandwinning voor de Hollandse en Zeeuwse kust. Publicatiereeks Grondstoffen 2004/1. Expertisecentrum Bouwstoffen, Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, Delft, 108 p.

Floods in the Meuse basin: contribution of tributaries

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Abstract

If a flood wave of a river coincides with flood waves of tributaries, extreme floods can occur. The floods of 1993, 1995, 2002 and 2003 in the Meuse basin are analysed to see if patterns can be derived with regard to peak convergence. The data show that a flood wave in the Meuse basin is generated at different locations and at different times; this is due to differences in precipitation patterns and geographical features of the area. The Meuse discharge at Borgharen often peaks before the discharge at Ampsin and Chooz, which are both located upstream of Borgharen. Due to occurrence of different flood waves during a flood event, measures taken to reduce peaks at one place along the Meuse can have negative effects on the peak discharge at other places along the Meuse. Hence, flood management should be done at basin level.

Figure 1. The Meuse basin with locations of monitoring stations and tributaries mentioned in Figure 2. The monitoring stations used in this study are only a selection out of the total number of monitoring stations that are operated at the different hydrological and meteorological institutes

Introduction

In the last decade the frequency and magnitude of floods in the Meuse basin have been relatively large. The volume of these floods is mainly influenced by initial storage volume and precipitation volume. The shape is largely determined by hydraulic properties of the river network and the convergence of flood waves of the main river and its tributaries. If the flood wave of the river coincides with flood waves of tributaries extreme floods can occur. This motivates the need to tune flood management of the river and the tributaries. Aim of the study is to analyse how flood waves of the Meuse and tributaries coincide during floods. The main question is: Which interaction patterns between the Meuse and the tributaries can be derived from the flood data of 1993, 1995, 2002 and 2003 and how can this be implemented within the objectives of the “Flood Action Plan” for the river Meuse? The information obtained allow for a quantitative analysis of hydrological processes under extreme conditions for the entire Meuse basin (Fig. 1). A similar study was performed Meuse basin (i.e. Limburg only).

Material and methods

The flood data used in this study consist of precipitation and hourly discharge data from gauging stations located in 14 tributaries and at 10 locations on the Meuse, of which three in France, eleven in Belgium, two in Germany and eight in the Netherlands. The data for this study are provided by DIREN, MET-SETHY, Staatlicher Umweltamt, AWZ and RWS.

For the different stations, the time of occurrence of peak discharge was determined; the peak time. As some stations are not located at confluences of the Meuse and tributaries, the peak time was corrected with the propagation time of a flood wave from station to confluence. In case data was lacking, this time was estimated. Secondly the time difference between the Meuse flood wave passage at the confluence and the discharge peak time of the tributary was determined (Fig. 2). Results provide information whether Meuse and tributary peaks coincide. Finally the actual (discharge at the confluence during passage of the floodwave in the Meuse) and potential (observed peak discharge) contribution of the tributaries were determined. This allows a quantitative analysis of the contribution of the tributaries to the peak discharges at Chooz, Ampsin and Borgharen.

Semois. The Lesse and Sambre cause the peak discharge at Ampsin. For the discharge at Borgharen the contribution of the Ourthe, Sambre, Lesse and Amblève are significant.

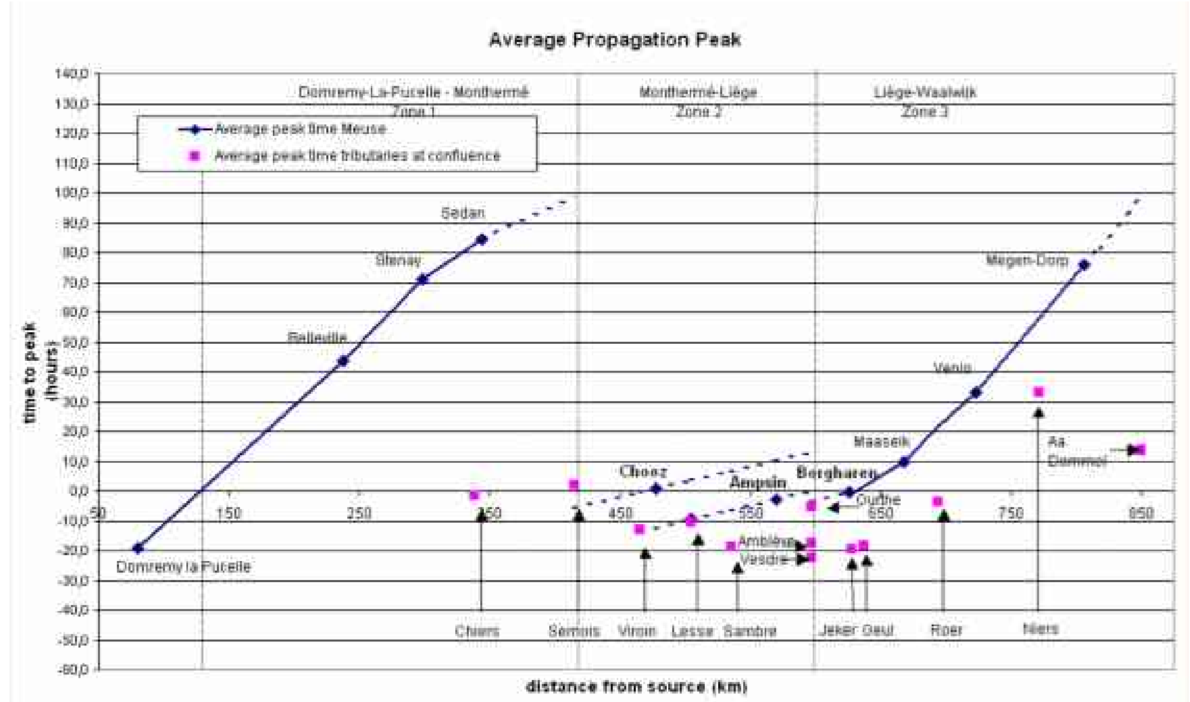

Figure 2. Average propagation of discharge peaks in the Meuse basin

Results

Geographically, the Meuse basin can be divided in 3 zones. In zone 1 and 3 the river flows through a wide river valley; in zone 2 the river valley is narrow and steep. As a result, the propagation time of the flood wave is much longer in zones 1 and 3 than in zone 2. Figure 2 shows average peak times at the different locations with Borgharen as reference (t=0), plotted against the distance. The dotted line displays the assumed peak time of a location. This line is estimated, assuming propagation times in the Meuse (zone 2) that are based on general observations (Berger, 1992). It would be better to perform this analysis with hydraulic models, but that is beyond the scope of this study.

Analysis of the peak times shows that the tributaries in zone 2 on average peak before the tributaries in zone 1 and zone 3, mostly before the Meuse peak passage. However in zone 2 it may occur that the flood wave on the Meuse is generated only by the discharge of the tributaries. This explains the generation of different flood waves. The peak discharges of the Lesse, Sambre and Ourthe often coincide with the peak on the Meuse. The peak discharge at Chooz is caused mainly by the

The discharge of zone 1 becomes more significant for the discharge at Borgharen if the flood period extents due to a sequence of precipitation events. Also some patterns with regard to peak order can be derived. For the events considered it appears that the discharge of the Ourthe system peaks in sequence: Vesdre, Amblève and Ourthe.

Discussion of uncertainties

The propagation time differs for every flood. However by assuming a constant propagation time for some tributaries, this is not taken into account and peak times at confluences can differ a few hours. For example, in reality the peak lines of Ampsin and Borgharen could be connected, but due to limiting data no univocal picture can be derived. In this study the time of maximum discharge at a station is taken as the peak time. In reality the considered discharge differs only little from the discharge in the hours before or after the peak. Thus, if the lag between Meuse peak and tributary peak is small (e.g. 3 hours), than the peaks virtually coincide.

The discharge data used are measured at the tributary stations; in reality the discharge confluencing with the Meuse is larger. The information needed to correct the discharge is not available. Furthermore, due to differences in discharge (hourly) and precipitation (daily) records, it is not possible to determine an exact time of concentration of sub-catchments. In a next step of this study precipitation data will be included to support the discharge analysis.

Conclusion

The analysis presented here shows the general pattern of the confluence of flood waves in the Meuse basin. Due to the occurrence of different flood waves during a flood event, measures taken to reduce peaks at one place along the Meuse can have negative effects on the peak discharge at another place along the Meuse. This study can be used as a first inventory needed to tune measures that aim at a reduction of flood risk at the scale of the entire Meuse basin.

References

De Wit, M., R. van der Veen & L. van Hal, 2004. Samenvallen hoogwaterpieken Maas en zijrivieren, RIZA-werkdocument 2004.126x, RIZA, Arnhem.

Berger, H.E.J., 1992. Flow forecasting for the River Meuse, Ph.D. thesis, Delft University of Technology, Delft.


ct Assessment (CEA) of physical
and land use changes on riverine
floodplains

Application of a weather generator to simulate extreme river discharges in the Rhine and Meuse basins

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Abstract
A weather generator has been developed to simulate long-duration sequences (1000 years or more) of daily discharges using a hydrological/hydraulic model. Resulting extreme value distributions of 10-day rainfall amounts and daily river discharges are discussed.

Introduction
The traditional method for the estimation of the design discharge is based on the extrapolation of the distribution of recorded annual discharge maxima to a mean return period of 1250 years. Disadvantages of this method are that strong extrapolation is required, and that discharge records are potentially inhomogeneous. Furthermore, considering annual discharge maxima gives no insight in the shape and duration of the flood peaks. Since the mid-1990s a new methodology is under development, which aims at the simulation of long-duration discharge sequences. Besides a hydrological model (HBV) and a hydraulic model (SOBEK), also a stochastic weather generator is involved to synthetically generate realistic long daily sequences of rainfall and temperature for the river basin.

The weather generator
Rainfall and temperature at different locations in the drainage area are simultaneously simulated by 'nearest-neighbour' resampling. A major advantage of this resampling method is that both the spatial association of daily rainfall over the drainage basin and the dependence between daily rainfall and temperature are preserved, without making assumptions about the underlying joint distributions. To incorporate autocorrelation, one first searches the days in the historical record (here 10), whose characteristics are most similar to those of the previously simulated day, referred to as 'nearest neighbours'. One of these nearest neighbours is then randomly selected using a decreasing kernel and the observed values for the day subsequent to that nearest neighbour are adopted as the simulated values for the next day. The search for nearest neighbours of the previously simulated day is based on quantities like the basin-average rainfall and temperature for that day, the rainfall total of the preceding four days and the fraction of the basin for which the daily rainfall exceeds the wet-day threshold of 0.3 mm. The effect of seasonal variation is reduced by restricting the search for nearest neighbours to days within a moving window of 61 days, centred on the calendar day of interest. The variables being simulated do not necessarily play a role in the selection of nearest neighbours (e.g. areal rainfall for a sub-catchment) but are supposed to be closely related to those variables influencing the selection. More details about nearest-neighbour resampling can be found in Buishand & Brandsma (2001).

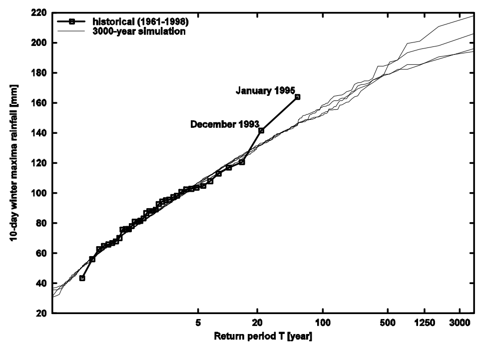

Figure 1. Gumbel plot of winter maxima (historical and simulated) 10-day basin-average rainfall for the Meuse.

Results
Figure 1 compares the distribution of the 10-day winter maxima of basin-average rainfall for four 3000-year simulations for the Meuse basin with the corresponding distribution of the historical winter maxima (October through March) for the period 1961-1998. These extremes are considered because large river discharges are often caused by large multi-day rainfall amounts in winter. The figure shows that the weather generator is capable of reproducing the distribution of the 10-day rainfall extremes well. Furthermore, the historical maximum 10-day rainfall amounts is largely exceeded in the simulations. It is

expected that this leads to higher flows than those observed. Figure 2 displays the distribution of annual maxima of daily discharge for the Rhine at Lobith from three 50-year simulations, to which Gumbel distributions are fitted. Large differences between the simulations are found if these distributions are extrapolated to return periods in the order of 1000 years. Figure 3 shows the same for three simulations of 1000 years, except that three-parameter GEV distributions are fitted to the data. These show a considerably smaller spread for long return periods.

Conclusions

The weather generator reproduces observed properties of extreme rainfall well and is also capable of simulating more extreme events than have been observed in the past. Large extrapolation of distributions fitted to observed discharge maxima are very uncertain. The use of a weather generator with a hydraulic/hydrological model can help reduce the uncertainty in the estimated extreme flows for long return periods.

Reference

Buishand, T.A. & T. Brandsma, 2001. Multi-site simulation of daily precipitation and temperature in the Rhine basin by nearest-neighbor resampling. Water Resources Research 37, pp. 2761-2776.

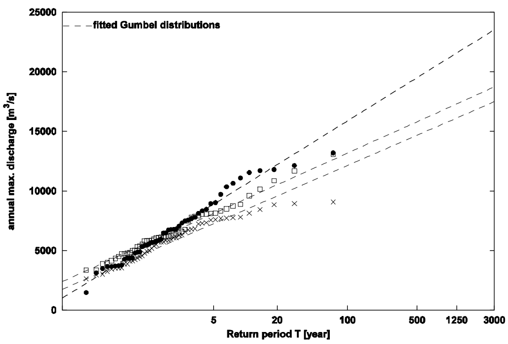

Figure 2. Gumbel plot of annual maxima of daily discharge of the Rhine at Lobith from three 50-year simulations.

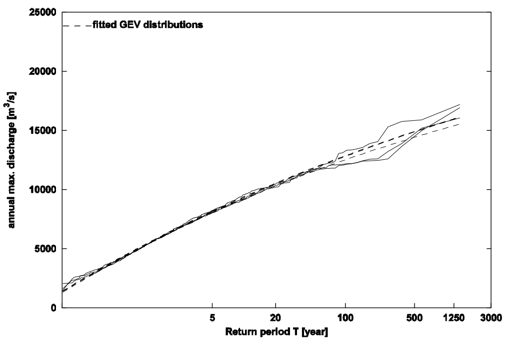

Figure 3. Gumbel plot of annual maxima of daily discharge of the Rhine at Lobith from three 1000-year simulations.

A 3,000 year discharge simulation in the Meuse basin with a stochastic weather generator and the HBV model

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Abstract
A stochastic weather generator which generates long-term rainfall and temperature records has been linked to the hydrological model HBV to provide more insight in the estimation of design discharges. This study summarizes the results of the application of the rainfall generator in the Meuse basin. Therefore, a discharge simulation of 3,000 years has been performed.

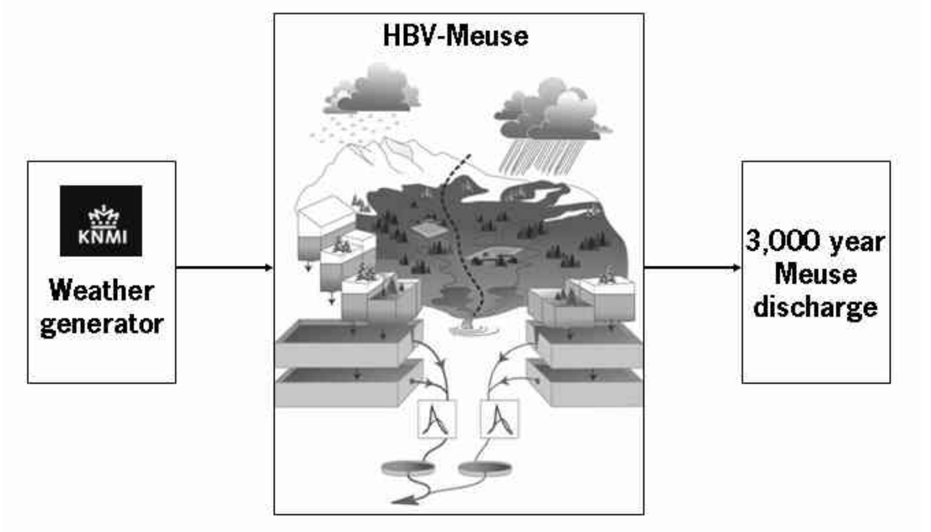

Figure 1. Schematized image of rainfall generator methodology

Introduction
Flood protection along the main Dutch rivers is based on design water levels with a given probability of exceeding. The estimation of the design discharges is currently based on the extrapolation of the measured discharges at Borgharen (Meuse) and Lobith (Rhine). However, the determination of design discharges from statistical analyses of the measured peak discharges faces various problems. First, it is unknown how representative the relatively short measured discharge records are. Secondly, the discharge record is potentially non-homogeneous because of changes in the upstream basin, the river geometry and climate. Third, the choice of frequency distributions is also a point of uncertainty. Therefore, a new methodology has been proposed to provide a better physical basis for the estimation of the design discharge of the Dutch rivers. This new methodology is known as rainfall generator.

Rainfall generator for the Meuse basin
The application of the rainfall generator for the Meuse basin consists of a KNMI stochastic weather generator linked to the hydrological HBV-Meuse model (Fig. 1). KNMI generated a 3,000 year record of precipitation and temperature data for the entire Meuse basin (Leander & Buishand, 2004). This record has been routed through the rainfall-runoff module of the HBV-Meuse model resulting in a discharge record containing 3,000 years of daily discharge data.

Results

Figure 2 contains 3,000 annual discharge maxima (daily values) derived from the rainfall-runoff simulation using input of the weather generator. The dots show a random temporal distribution and no trend was found in the simulated data record. The generated dataset shows an underestimation in the highest range of the annual discharge maxima if fitted to a Gumbel distribution (Fig. 3). However, the figure also shows that the rainfall generator resulted in peak discharges larger than historically observed.

Conclusions

The simulation of 3,000 years shows that the rainfall generator is capable of generating extreme discharge events that are larger than observed. A Gumbel plot of annual daily discharge maxima derived from measured and generated records reveals that extremes are hard to fit. This counts both for the observed extremes (1993 and 1995) and the generated extremes.

Reference

Leander, R. & T.A. Buishand, 2004. Rainfall generator for the Meuse basin; development of a multi-site extension for the entire drainage area. KNMI-publication 196-III, De Bilt.

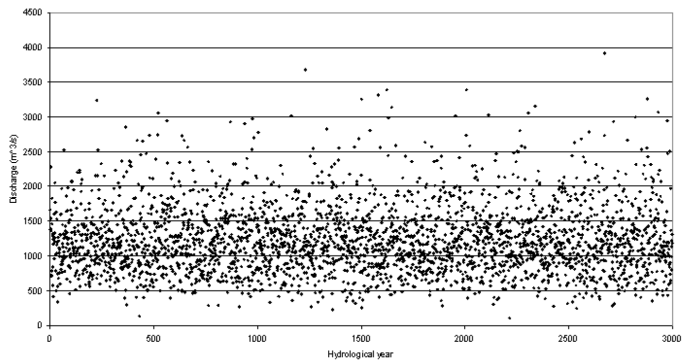

Figure 2. Simulated annual discharge maxima (daily values).

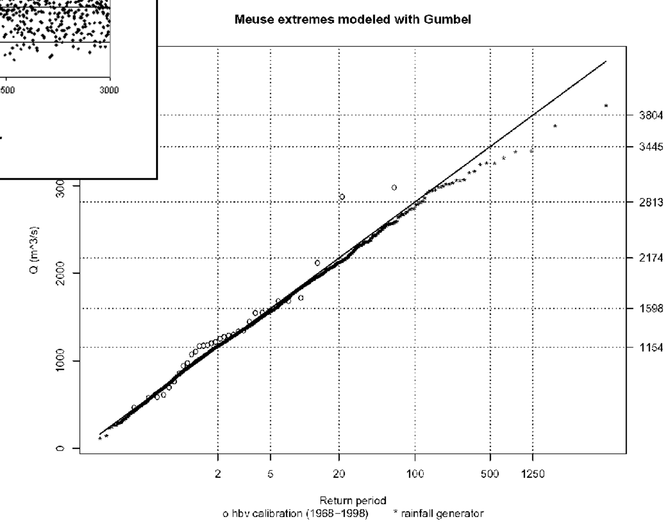

Figure 3. Gumbel plot of annual daily discharge maxima (m^3/s) calculated by HBV for measured (dots) and generated (stars) meteorological input data

A quick scan forecasting tool for pre-screening probabilistic weather forecasts on their seriousness

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Abstract
The flood forecasting model FEWS-Rhine is capable of computing discharges with lead times of 10 days, including computation of weather uncertainties induced by EPS weather forecasts. However, the computation time needed is too large. A quick scan tool was developed in this study to give a first indication of discharges induced by EPS weather forecasts. Three simplifications with regard to FEWS-Rhine were applied: (1) rainfall runoff modelling was lumped per sub-basin, using the HYMOD rainfall runoff model structure; (2) river routing was based on a multiple linear regression equation containing discharges in sub-basins upstream from Lobith in the preceding days; (3) only three sub-basins were included in the regression equation (Lippe, Mosel and Neckar) since discharges between neighbouring sub-basins are strongly auto-correlated. Calibration and validation scores prove that quite accurate daily averaged results can be obtained using these modelling simplifications. The computation of discharges from EPS weather forecasts shows a considerable amount of bias, partly due to anomalies in the model but mostly due to inaccuracies in the predictions of the precipitation intensity by EPS.

Introduction and problem description
Since the floods in 1993 and 1995 in the Rhine and Meuse basins, efforts have been put into the improvement of flood forecasting systems and extension of lead time. For the Rhine basin, the last forecasting system produced is FEWS-Rhine, developed by WL | Delft Hydraulics and RIZA. It enables the forecasting of floods at Lobith 10 days ahead using weather forecasts and water-level recordings as input.

The large lead times result in a larger influence of weather uncertainties on discharge forecasts. Therefore, the computation of discharges from EPS (Ensemble Prediction System) weather forecasts was enabled in FEWS-Rhine. EPS computes different possible weather states from perturbed initial conditions. The EPS of the European Centre for Medium range Weather Forecasts produces 50 possible weather states, called 'ensemble members'. A disadvantage of the ensemble computations is that it takes too much computation time to run all EPS members for purposes of real-time flood forecasting. Therefore, the objective of this study is to define a quick scan tool to obtain a first estimate of daily averaged discharges resulting from full EPS forecasts.

Description of simplified model
Three simplifications were applied with regard to the FEWS-Rhine model.

- The distribution of the modelling of sub-basins of the Rhine over several rainfall runoff models, was aggregated into one lumped model per sub-basin. Instead of the HBV structure, the HYMOD structure (Vrugt et al., 2002) was used for modelling. It contains routines for snow, sub-surface flow and groundwater flow (Fig. 1).
- The SOBEK model between Maxau and Lobith was replaced by a multiple linear regression equation containing discharges from sub-basins upstream from Lobith in the preceding days and the discharge at Lobith at *time* = *t* – *1*. The lag times that are taken into account in this model are based on travel times between Lobith and the confluence of the Rhine and its major tributaries.
- The discharges between neighbouring sub-basins are assumed to be auto-correlated due to similarities between hydrology and meteorology, which is especially the case in winter periods. This makes it possible to exclude auto-correlated sub-basins from computation in the regression equation. Only discharges

from the Lippe, Mosel and Neckar are included.

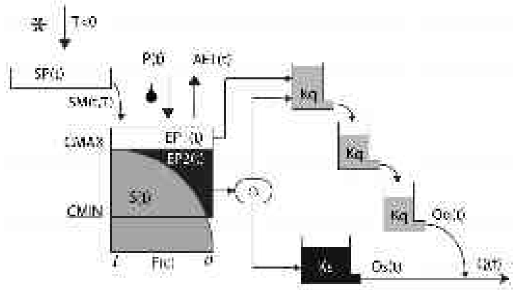

Figure 1. HYMOD rainfall runoff model including a snow routine. The states and parameters in the HYMOD structure: T = Temperature (deg. C); SP = Snowpack (mm); SM = Soil moisture (mm); P = Precipitation (mm/day); AET = Actual Evaporation (mm/day); EP1 = Excess rainfall 1 (mm/day); EP2 = excess rainfall 2 (mm/day); S(t) = Average soil moisture (mm); F(c) = Distribution of field capacity over the watershed (-); CMAX = maximum field capacity (mm); CMIN = soil moisture at location where F = CMAX (mm); alpha = separation coefficient of excess rainfall over quick flow and slow flow zones (-); Kq = Quick flow recession constant (day^{-1}); Ks = Slow flow recession constant (day^{-1}); Qs = Slow flow (m^3/s); Qq = Quick flow (m^3/s); Q = Total flow (m^3/s).

Calibration

Calibration of the rainfall runoff models was carried out by trial and error using the Nash/Sutcliff criterion as objective function. A calibration data set of October 1997 until December 1998 was used. The models were validated on a data set of September 1994 until February 1995.

The regression equation was derived by setting up a matrix containing discharges from the three sampled sub-basins at *time = t – travel time to Lobith* and a vector, containing discharges at Lobith at *time = t*. The regression coefficients that described the best fit were derived using the least squares method. Results from the regression equation are presented in Figure 2.

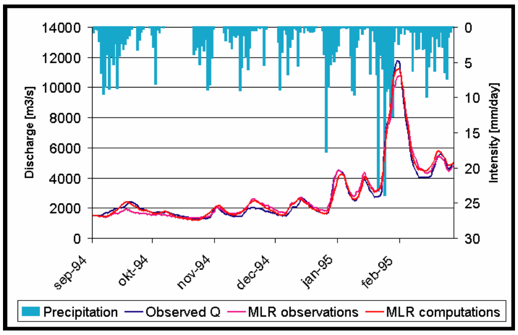

Figure 2. Calibration time series of the model for Lobith, September 1994 - February 1995.

EPS results

Computation of the EPS forecast of January 21, 1995, which should describe the flood of 1995, shows a considerable amount of bias, which is partly caused by the regression equation and bias in the rainfall runoff models but for the largest part by underestimations of the precipitation intensity by the EPS system (Fig. 3). Due to inaccuracies in the EPS system, the spread in EPS in the first two days of forecasting is unreliable. Therefore it could be considered to use only a high-resolution deterministic weather forecast for the first two days.

Conclusions

- A model concept based on linear regression technique containing only samples of sub-basin discharges as variables can produce quite accurate daily averaged discharges at Lobith.
- This model concept is able to produce a quite accurate indication of probability of occurrence of floods at Lobith, according to EPS forecasts.
- Compared to the physical model FEWS-Rhine, this model is able to compute an EPS forecast with a lead time of 10 days within a much shorter computation time.
- EPS computations show some bias in peaks, which is partly caused by anomalies in the hydrological model, and partly by average underestimation in precipitation intensity by EPS.

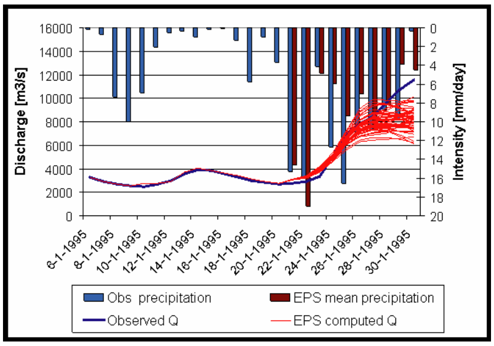

Figure 3. EPS-driven hindcast of the 1995 flood event at Lobith using the EPS quick scan tool

Reference

Vrugt, J.A., W. Bouten, H.V. Gupta & S. Sorooshian, 2002. Toward improved identifiability of hydrologic model parameters: the information content of experimental data. Water Resources Research 38 (12), 1312, doi:10.1029/2001WR001118.

Hydrological application of areal rainfall estimates from the Wideumont weather radar over the Ourthe catchment: preliminary results

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Abstract
This paper presents a first assessment of the hydrometeorological potential of a C-band doppler weather radar recently installed by the Royal Meteorological Institute of Belgium near the town of Wideumont in the southern Ardennes region.

Introduction
Wageningen University (WU), the Royal Meteorological Institute of Belgium (RMI) and the Hydrological Service of the Walloon Region of Belgium (MET-SETHY) have recently established a research collaboration to investigate whether an improved assessment of the space-time structure of precipitation, as can be obtained with the newly installed weather radar in Wideumont, will lead to an improved understanding of the hydrometeorology of Ardennes catchments, in particular the Ourthe (Berne et al., 2005).

Figure 1. Ourthe catchment upstream of Tabreux (1597 km^2) with the location and elevation (meters above sea level) of the 10 MET-SETHY rain gauges and a cartesian 1km x 1km grid resampled from the polar data of the Wideumont weather radar (located near the southern border of the catchment)

Methods and materials
The Royal Meteorological Institute of Belgium (RMI) recently installed a new Gematronik C-band doppler weather radar near the town of Wideumont (535 m.a.s.l.), in the southern Ardennes area (Province of Luxemburg), close to the border with the Grand Duchy of Luxembourg. The radar, which is installed on a 50 m high tower, performs every 15 min. a 10-elevation volume scan of the 3D structure of the rainfall field out to a distance of 240 km and similarly a doppler scan to a range of 120 km. The range resolution of the radar data is typically 0.5 km. An operational precipitation product is generated every 5 min.

To perform a first assessment of the hydrological potential of the Wideumont weather radar, the Ourthe catchment upstream of Tabreux was selected as study area. Figure 1 shows the 1597 km^2 catchment with the location and elevation of the 10 MET-SETHY rain gauges covering the area. Also included is a cartesian 1x1 km^2 grid resampled from the polar volume scan reflectivity data of the Wideumont weather radar, which is located near the southern tip of the catchment. Two rainfall events were considered, namely the rainfall-runoff events of 4-10 May 2002 and 1-7 March 2003. MET-SETHY kindly provided hourly raingauge and discharge data for the Ourthe at Tabreux for these events.

RIZA kindly provided the opportunity to run a fully calibrated HBV-model (Lindström et al., 1997) of the Ourthe catchment. A 30-year calibrated HBV model parameter data set from RIZA (1968-1998) was employed to choose "optimal" initial conditions for both selected events by searching in the database for analogous hydrographs during the month preceeding the discharge events, employing the Nash-Sutcliffe parameter as an error criterion (Ten Heggeler, 2004).

Results and discussion
The mean areal rainfall estimated from the second elevation of the Wideumont weather radar volume scan reflectivity data using the standard Marshall-Palmer reflectivity-rain rate relation (without adjustment to rain gauges) showed a 42% underestimation with respect to the gauge average rainfall for 4-5 May 2002 and a 12% underestimation for 1 March 2003 (Table 1). The second rather than the first elevation was employed to minimize the possible adverse effects of ground clutter.

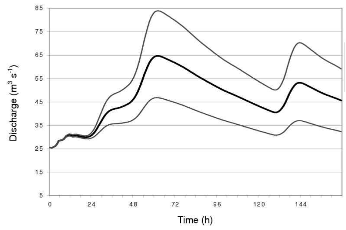

Figure 2. Uncertainty in the discharge at Tabreux for the period 1-7 March 2003 calculated using the (lumped) HBV-model due to uncertainty in the mean areal rainfall. The black line indicates the discharge calculated using the mean areal rainfall from the 10 rain gauges, the gray lines correspond to the discharges calculated using the 20% and 80% uncertainty limits on the mean areal gauge-derived rainfall over the 1597 km² catchment area (Fig. 1).

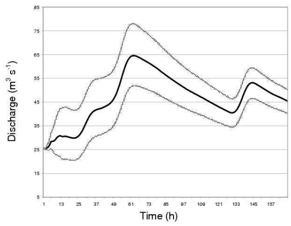

Figure 3. Sensitivity of the simulated discharge at Tabreux for the event of 1-7 March 2003 due to an uncertainty of ±5 mm in the initial content of the fast runoff reservoir of the HBV model. The black line indicates the discharge calculated using the mean areal rainfall from the 10 rain gauges (identical to the black line in Fig. 2), the gray lines correspond to the discharges calculated using a 5 mm increase and a 5 mm decrease in the initial content of the fast runoff reservoir (UZ).

The observed underestimation may be attributed to an erroneous reflectivity-rain rate relation and/or to rain-induced attenuation. Obviously, application of the radar-estimated mean areal rainfall to the gauge-calibrated HBV-model for the Ourthe upstream of Tabreux produced an underestimation of the predicted with respect to the measured discharge for the event of 4-10 May 2002. A similar analysis for 1-7 March 2003 was impossible because the available radar data covered only one day.

Recall that HBV is a lumped rainfall-runoff model, in principle not ideal to assess the impact of spatial rainfall variability of precipitation. Nevertheless, in this limited setting there is still an interesting application of the power of weather radar, namely its spatial coverage. Approximately 1600 1x1 km² radar pixels cover the Ourthe basin upstream of Tabreux. In a Monte Carlo simulation framework one can assume the radar data to represent the actual rainfall field (1600 “rain gauges”) from which a “true” areal average rainfall can be calculated. Also, one can randomly pick (without replication) 10 “gauges” from the 1600 pixels and compute the arithmetic mean of those 10 numbers. This random drawing can be repeated say 1000 times to assess (in a very simple fashion since gauge locations are chosen independently without imposing for instance a minimum inter-gauge distance) the uncertainty in estimating the areal average rainfall over a 1600 km² catchment from only 10 hourly gauge observations.

The resulting sampling distribution of the mean areal rainfall appears to be nearly symmetrical. In addition, the ratios of the quantiles with respect to the “true” mean areal rainfall appear to remain remarkably constant over time during the events considered. It turns out that the hydrological uncertainty associated with this rainfall sampling uncertainty (±25% on an hourly basis, see Fig. 2) is of the same order of magnitude as the uncertainty associated with the initial conditions as estimated from the 30-year database (Fig. 3).

Conclusions and recommendations

The mean areal rainfall over the ~1600 km² Ourthe catchment upstream of Tabreux estimated from the Wideumont weather radar using the standard Marshall-Palmer reflectivity-rain rate relation (without adjustment to rain gauges) shows biases between +128% and -42% with respect to the corresponding gauge estimates for six selected precipitation events. For two rainfall events the radar-estimated mean areal rainfall is applied to the gauge-calibrated (lumped) HBV-model for the Ourthe upstream of Tabreux, resulting in a significant underestimation with respect to the observed discharge for one event and a closer match for another.

The uncertainty in the hourly discharge from the ~1600 km² Ourthe catchment upstream of Tabreux associated with the sampling uncertainty of the mean areal rainfall estimated from 10 rain gauges evenly spread over the catchment amounts to ±25% for the two events analyzed. This uncertainty is of the same order of magnitude as that associated with the initial conditions.

The development of accurate and robust procedures for correcting for rain-induced attenuation and the vertical profile of reflectivity is the topic of ongoing investigations. The major floods which occurred during the 2002-2003 winter season will be studied as part of the ongoing collaborative research project. We also foresee a comparison of HBV with runoff estimates from the Hydromax river flow forecasting model, which is currently used operationally at MET-SETHY.

Acknowledgements

The second author acknowledges financial support from the European Commission through a Marie Curie Postdoctoral Fellowship (Contract EVK1-CT-2002-50016). The third author acknowledges financial support from the Netherlands Organization for Scientific Research (NWO) through a Vernieuwingsimpuls/VIDI grant (Project 016.021.003). The collaboration between WU, RMI and MET-SETHY is supported by the European Commission as part of Integrated Project FLOODsite (Contract GOCE-CT-2004-505420, see also http://www.floodsite.net/).

References

Lindström, G., B. Johansson, M. Persson, M. Gardelin & S. Bergström, 1997. Development and test of the distributed HBV-96 hydrological model. J. Hydrol. 201, pp. 272-288.

Ten Heggeler, M., 2004. Hydrological modelling and areal average rainfall estimates of the Ourthe catchment derived from the wideumont weather radar and precipitation gauges. M.Sc. thesis, Wageningen University.

Table 1. Characteristic precipitation events selected by the RMI, the corresponding total mean areal rainfall accumulations over the Ourthe catchment upstream of Tabreux as derived from radar and raingauges, and the resulting bias of the uncorrected radar rainfall estimates with respect to the gauge estimates

Date	Type of event	Radar (mm)	Gauges (mm)	Bias (%)
4 May 2002	convective	19.1	32.7	-42
0 July 2002	convective	10.2	9.8	+4
19 August 2002	convective	7.3	3.2	+128
24 November 2002	stratiform	9.1	7.6	+20
30 January 2003	stratiform	4.2	2.4	+75
1 March 2003	stratiform	9.1	10.3	-12

Learning from the data: a stepped calibration approach

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Abstract
Following a 'top-down' modelling approach a model structure has been developed based on an analysis of the observed discharge at a stream-gauge station in Luxembourg. Individual model components have been identified starting with a simple structure, and increasing model complexity when the model showed some difficulties in matching observations.

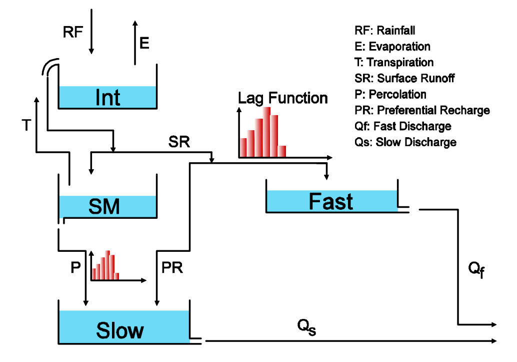

Figure 1. Model structure

Introduction
The 'top-down' or 'downward' approach (Klemes, 1983; Sivapalan, 2003) in a cause-effect relationship can be considered as the process of analyzing the effects and trace back to the causes that might have generated them. The 'bottom-up' or 'upward' approach would perform the opposite operation, starting from the causes and combining them trying to achieve the desired effect. The 'top-down' approach can be considered as a strategy of learning from data.

In the present case, we adopted the 'top-down' approach in the development of a conceptual model structure, starting from a simple concept and adding or modifying progressively in an iterative way processes and components. Modifications have been considered based on physical reasoning, and have been applied when model performances in reproducing observations could be improved.

A model structure developed in this way involves components and parameters that can be directly associated to specific hydrograph characteristics. In the calibration phase those parameters should be adjusted to match the hydrograph characteristics that they presumably influence.

To perform this operation we think that, instead of an 'all-at-once' calibration approach, where all parameters are calibrated together in a single optimization run, a stepped approach would be more appropriate.

The stepped approach proposed here consists of: (1) associating some model parameters with specific physical processes that can be identified analysing the recorded time series; (2) defining some objective functions that represent performance measures for specific hydrograph characteristics; (3) calibrating separately in an iterative manner each group of parameters associated with each objective function.

In this way we aim to overcome some problems that may arise when 'all-at-once' calibration approaches are used. When those approaches are applied, in fact, some parameters might be calibrated versus objectives on which they have little influence. This would cause some effects that we try to avoid, like the tendency of fitting certain aspects of the simulations at the expense of others, the generation large uncertainties for the representation of certain processes, and compensation of internal structure errors by parameter adjustment.

Methods
The conceptual model used consists of an interception component, a soil moisture reservoir, a fast reacting reservoir, and a slow reacting reservoir (Fig. 1). Two lag-functions are used to off-set the fluxes that enter the slow and the fast reservoir. A runoff coefficient dependent on the soil moisture reservoir separates infiltration from surface runoff Water reaches the fast reservoir by surface runoff, and the slow reservoir by percolation and preferential recharge.

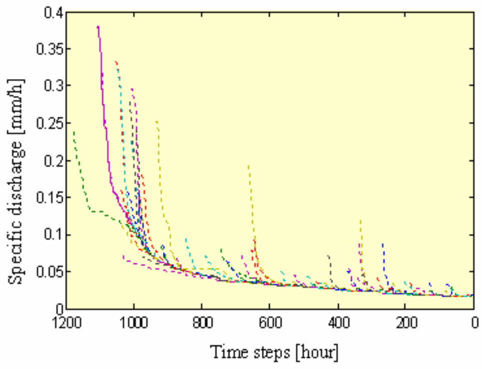

Figure 2. Master Recession Curve calculation.

The stepped approach is applied here to calibrate three key aspects of a hydrograph simulation: the low flow recession, the high flow events, and the lag time of the system. Groups of parameters and functional dependencies associated with each of those aspects are assessed independently in the following steps: (1) estimation of a Storage-Discharge relation for the slow reservoir by calculating a Master Recession Curve (MRC); (2) calibration of high flows by maximising the Nash Sutcliffe (NS) coefficient, which is sensitive to high flows; (3) calibration of time lags by maximising the correlation coefficient of simulated and observed discharge. After this a new estimate of the storage-discharge relation is made, by correcting the modelled percolation flux, and the procedure is repeated until convergence is reached. The model parameter defining the interception process is calibrated iteratively within a fixed feasible range within the second calibration step.

The MRC (Lamb & Beven, 1997) calculation consists of sorting hydrograph recessions into ascending order, based on the lowest tail-end discharge (Fig. 2). All recessions are then concatenated to form a single recession curve. This procedure excludes storm flow effects from the MRC. The MRC therefore represents the long-term recession of a catchment.

The first objective of the stepped approach is to have a model that has a response that is close to the MRC for low flows. For this reason we use the calculated MRC to determine a first estimate of the storage-discharge relation that we apply to the slow reservoir of the model. After that we calibrate other model parameters to maximise the Nash-Sutcliffe coefficient, which provides a good performance measure for high flow simulations, due to the square of the difference between observed and simulated discharge.

Subsequently, the lag time is calibrated to maximise the correlation coefficient. At this point a new estimate of the storage-discharge relation is calculated by taking into account the modelled percolation that enters the slow reservoir.

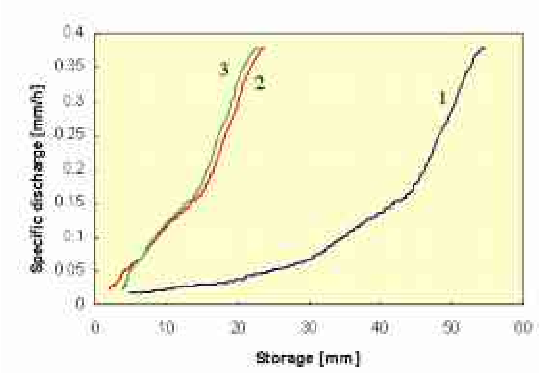

Figure 3. Storage-discharge relation for the slow reservoir calculated for three iterations.

Application

The procedure has been applied to the Hesperange catchment in Luxembourg (292 km^2), which is located upstream of Luxembourg City. Land use of the study area is dominated by pastures and forests, while the geology is characterised by Marls, Limestone and Sandstone. For calibration of parameters in the second and third calibration steps the Adaptive Cluster Covering algorithm (Solomatine, 1999) has been used.

Figure 3 shows the calculation of the storage-discharge relation for the slow reservoir based on the MRC. After three iterations the curves are already quite close, we therefore stop iterating. It is interesting to notice that while the first estimate of the storage-discharge relation resembles an exponential function, the second and third estimates are close to a linear function, suggesting that a linear reservoir applies. Hence, the non-linear reservoir of Lamb & Beven (1997), in our case, appears to be the result of percolation.

In Fig. 4 a simulation run is shown. Observed and simulated hydrograph and outflow from the slow reservoir are represented. Also the calculated MRC is represented. In recession periods the model follows the MRC quite closely (red line).

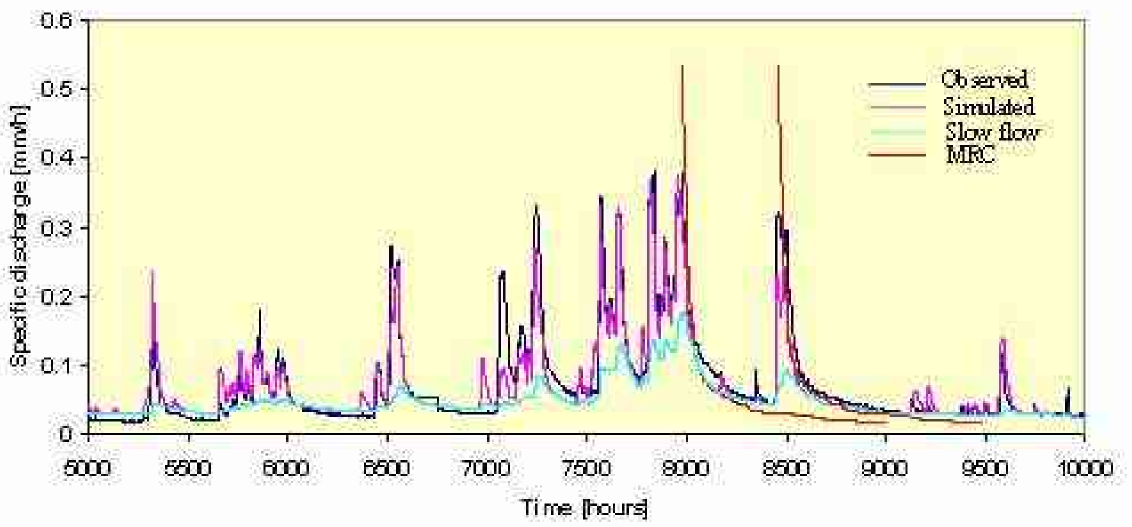

Figure 4. Hydrograph simulation at Hesperange

Conclusions

In this particular case the stepped approach was applied with good results, and, being integrated with a 'top-down' modelling approach, it has been useful to identify components and parameters that needed improvement. Therefore it helped the development of the model structure. We believe that the application of such an approach gives best results when model parameters can be associated with specific processes that can be separately calibrated.

References

Klemes, V., 1983. Conceptualization and scale in hydrology. Journal of Hydrology 65, pp. 1–23.

Lamb, R. & K.J. Beven, 1997. Using interactive recession curve analysis to specify a general catchment storage model. Hydrology and Earth System Science 1, pp. 101-113.

Sivapalan, M., G. Blöschl, L. Zhang & R.

Vertessy, 2003. Downward approach to hydrological prediction. Hydrological Processes 17, pp. 2101-2111.

Solomatine, D.P., 1999. Two strategies of adaptive cluster covering with descent and their comparison to other algorithms. Journal of Global Optimization 14(1), pp. 55–78.

Towards a grid-based regionalisation of storm flow coefficients

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Introduction

Flood awareness in the Grand Duchy of Luxembourg became apparent after the major floods of 1993 and 1995. In 1996 a start was made by the public authorities to develop a dense measuring network throughout the Grand Duchy of Luxembourg to gain insight in groundwater and surface water behaviour. In our study we improved a method, originally developed by Pfister et al. (2002), to identify basins that are capable of high runoff production. For this purpose basin specific storm flow coefficients were calculated with a view to regionalization.

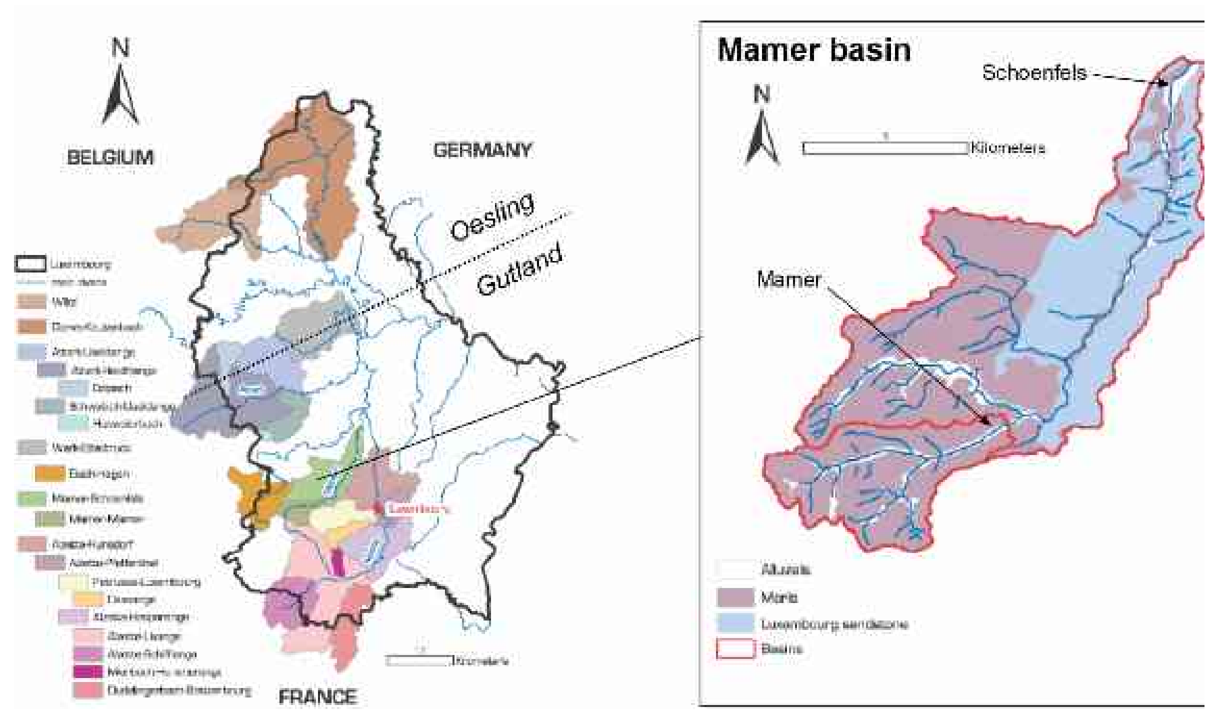

Figure 1. The Grand Duchy of Luxembourg, the location of the Mamer River basin and the lithology of the Mamer River basin.

Study area

The study area lies within the Grand Duchy of Luxembourg and is part of the Mosel basin (Fig. 1). It contains 29 gauged basins varying in size from about 4 km^2 up to 1000 km^2. Rainfall data is collected at 14 meteorological stations throughout the study area. Both rainfall and discharge are recorded on a 15-minute time step. The amount of yearly rainfall is about 800 mm and the rainfall patterns are characterised by a strong negative West East gradient. Furthermore, rainfall totals are higher in the northern part than in the southern parts of the country. The basins are located on different lithological substrata. The northern part of the country, which belongs to the Ardenne massif, is called Oesling and here the dominant rocks are schists. Marls, sandstone and limestone represent the dominant lithology in the middle and south of the country, called the Gutland.

Methodology

In our study we improved a method to determine runoff-producing areas using storm flow coefficients. Pfister et al. (2002), developed this method for meso-scale basins with short hydrological data sets and it is able to classify basins on the basis of their response to rainfall. The method consists of five steps to determine the behaviour of meso-scale basins with a view to regionalise their specific storm flow coefficients: it comprises areal rainfall input (step 1) and storm flow separation (step 2) by a digital recursive filter technique (Nathan & McMahon, 1990). The storm flow coefficient C for the winter period is calculated by plotting storm flow and rainfall in a double mass plot for each basin (step 3). Then, a regression analysis is performed to determine the influence of lithology, land use and morphological properties of the basin on its specific storm flow coefficient (step 4). These parameter categories are commonly used in literature (Mazvimavi, 2003). With the equation derived from the regressions analysis it becomes possible to regionalise the storm flow coefficient C (step 5).

A final step, yet to be taken, is to apply the regression formula to a raster grid for the study area. It then should become possible to determine high runoff producing areas, independently from the physiographic characteristics of basins.

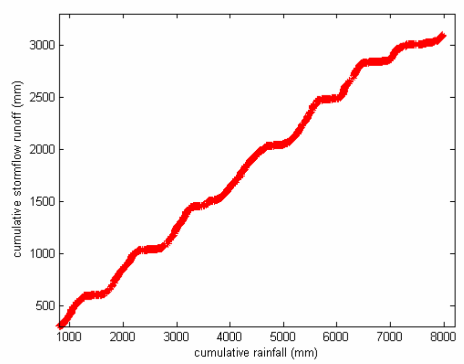

Figure 2. Cumulative storm flow-rainfall plot for the Eisch at Hagen; 6 years of measurements. The near-horizontal 'steps' represent summer periods, whereas the steep sections represent winter periods

Application

By plotting total storm flow and total rainfall for relevant events in a double mass curve a strong seasonal variation occurs. During summer the curve remains almost horizontal, implying low to very low storm flow coefficients. During the winter period a fairly constant slope is reached (Fig. 2). The storm flow coefficient C for a basin during this period is obtained by analysing the trend in the double mass curve for several years for winter periods only (Fig. 3). The steeper the slope of the double mass curve, the higher the storm flow coefficient. Furthermore, this storm flow coefficient is basin specific.

The C-value for two discharge stations in the Mamer River, one at Mamer and one at Schoenfels near the outlet of the basin, are respectively 0.72 and 0.55 (Figs 4 and 5). Upstream of Mamer, lithology consists of Marls; downstream the lithology is a combination of Marls and Sandstone (Fig. 1). Marls can be considered as an impermeable substratum, whereas sandstone as a substratum is fractured and the sandy weathered zone allows deep percolation.

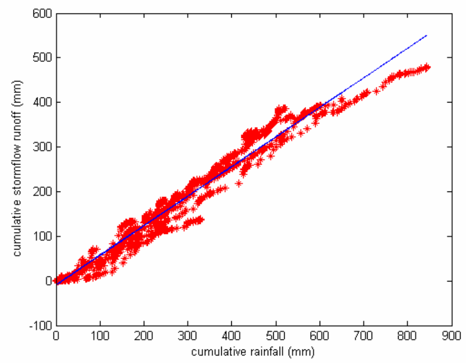

Figure 3. Cumulative storm flow-rainfall plot for the Eisch at Hagen (6 years of measurements; winter periods only; mean storm flow coefficient of all winter events = 0.6631).

This difference in lithology might be an explanation for the differences in C-values. To analyse the influence of other factors on the C-value a regression analysis was performed.

For the regression analysis 3 three parameter categories were selected: (1) lithology, (2) land use and (3) geomorphology. Each category has several parameters that will be used to explain the C-value. The first preliminary results from the regression analysis show that basin size is not strongly linked with the C-value. Relationships between all other parameters show a non-linear relationship with the C-value. The parameter for impermeability seems to be inversely correlated with the C-value.

Conclusions

The regression analysis as applied so far shows promising results. Also an analysis on the date of the inflection points in the double mass curve (i.e. the change from summer to winter conditions in the basins) indicates that basins behave differently in time. This, in combination with the C-value, can give extra information about the importance of the runoff producing areas. Once the regression formula is found it will be applied to a raster grid for the study area. We hope it then becomes possible to determine high runoff producing areas, independently from basins. The method's transferability will be tested on a larger scale by applying it in the region of the Rhineland-Palatinate (Germany).

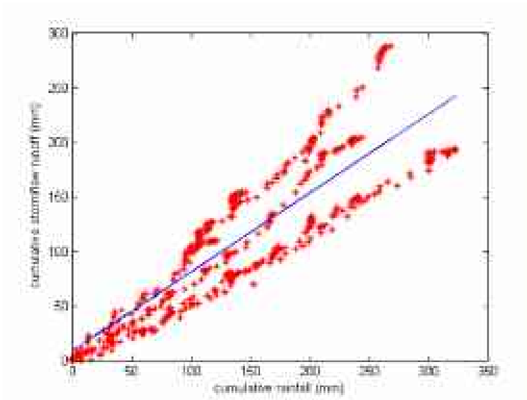

Figure 4. Cumulative storm flow-rainfall plot for the Mamer at Mamer (6 years of measurements; mean storm flow coefficient of all winter events = 0.7218)

References

Masvimavi, D., 2003. Estimation of flow characteristics of ungauged catchments. Ph.D. thesis, Wageningen University, Wageningen.

Nathan R. J. & T.A. McMahon, 1990. Evaluation of automated techniques for base flow and recession analysis. Water Resources Research 26 (7), pp. 1465-1473.

Pfister, L., J-F. Iffly & L. Hoffmann, 2002. Use of regionalized stormflow coefficients with a view to hydroclimatological hazard mapping. Hydrological Sciences 47, pp. 479-491.

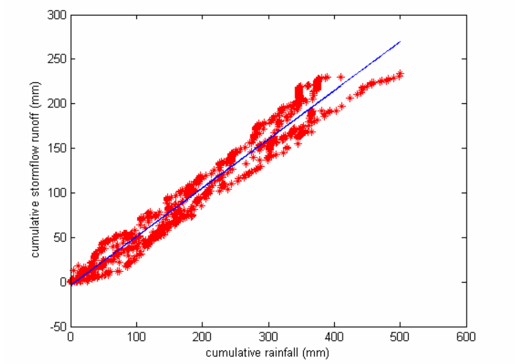

Figure 5. Cumulative storm flow-rainfall plot for the Mamer at Schoenfels (6 years of measurements; mean storm flow coefficient of all winter events = 0.5464)

Groundwater levels as state indicator in rainfall-runoff modelling using Artificial Neural Networks

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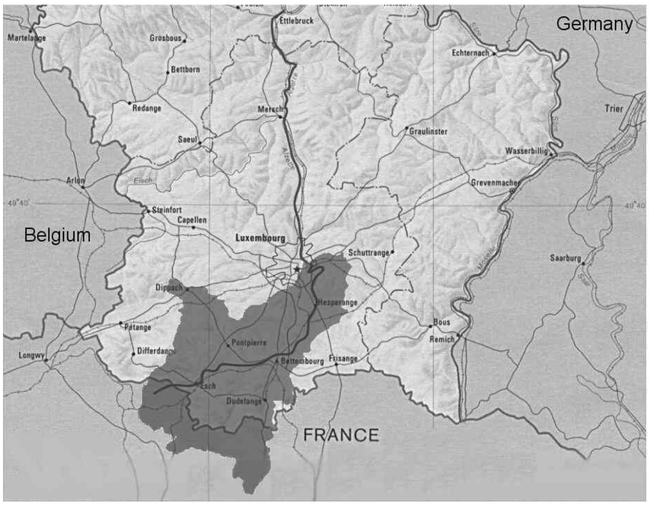
Abstract
Artificial Neural Networks (ANNs) have been successfully used for the simulation of rainfall-runoff behaviour in the Hesperange catchment (Luxembourg). Groundwater level information was used with the ANN models as an indicator of the hydrological state of the catchment and was found to be valuable as additional model input.



Catchment
Hesperange catchment, southern part of Alzette catchment
Catchment size: 270 km^2

Data
Daily values, 1996-2001
- Areal rainfall (P)
- Areal evaporation (E)
- Discharge at catchment outlet (Q)
- Groundwater level at one measurement station (GW)

Figure 1. Catchment and data.

Introduction
The various interacting processes that involve the transformation of precipitation into discharge are complex and spatially as well as temporally variable, which makes rainfall-runoff modelling using knowledge-driven approaches far from a trivial task (Beven, 2001). These approaches often suffer from excessive data requirements, large computational demands, and calibration problems. We therefore investigated the potential of a data-driven approach.

Data-driven rainfall-runoff modelling approaches are based on extracting and re-using information that is implicit in hydrological data, without directly taking into account the physical laws that underlie the hydrological processes. Our approach involved Artificial Neural Networks (ANNs), which have proven to be a successful modelling tool in various hydrological applications (ASCE Task Committee on Application of Artificial Neural Networks in Hydrology, 2000). We developed and tested multi-layer feedforward ANN models using a data set from the Hesperange catchment in Luxembourg (Fig. 1). Several design aspects of ANN modelling were investigated. Moreover, the influence of adding groundwater level information as additional model input was tested.

Artificial Neural Networks
ANNs (Fig. 2) use dense interconnection of simple computational elements, known as neurons. Optimisation algorithms attempt to optimise the ANN's internal structure (i.e. the weights on the internal connections) in a calibration procedure. The goal of most algorithms is to match the response of the ANN to sample input data with accompanying sample output data.

Advantages of ANNs are: (1) ability to simulate non-linearity; (2) no assumption of an a priori solution structure is needed (non-parametric technique);

(3) ability to discern relevant from irrelevant information;
(4) compactness, flexibility, and low computational demands.

Disadvantages of ANNs are: (1) some ANN design aspects have to be determined through trial and error; (2) training is complex; (3) good performance during training does not imply good operational performance.

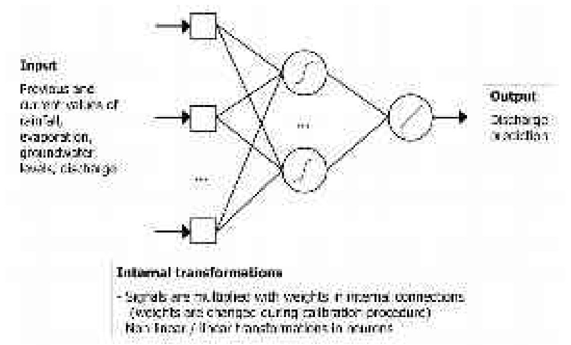


Figure 2. Multi-layer feedforward ANN for rainfall-runoff modelling

Rainfall-Runoff Modelling Using ANNs

ANNs can be used as empirical rainfall-runoff models by letting them simulate the relations between the input and output of a hydrological system (e.g. Hsu et al., 1995; Shamseldin, 1997; Rajurkar et al., 2004). The input signals to an ANN rainfall-runoff model should contain as much information as possible on the future discharge. Low or overlapping information content of input signals, however, may result in deteriorated performance. Some variables that are relevant to discharge prediction are listed in Table 1.

Table 1. Relevant ANN inputs for rainfall-runoff modelling.

Input variables	Information content
Rainfall	Driving force for runoff production
Evaporation, temperature	Losses in water balance, indicators of season
Previous discharge, groundwater levels, soil moisture, rainfall index	Indicator of hydrological state

ANN Design

In our study, we represented the dimension of time in the ANN model approach using tapped delay lines: multiple time series values over a certain window in time are presented as separate network input signals. ANNs with one hidden layer of neurons between the input units and output neuron were found to be effective and parsimonious model structures. The optimal number of hidden neurons in all ANN models was found to be around the square root of the number of input units. We chose the Levenberg-Marquardt algorithm for ANN training. This robust algorithm converged fastest and produced the most accurate simulation results

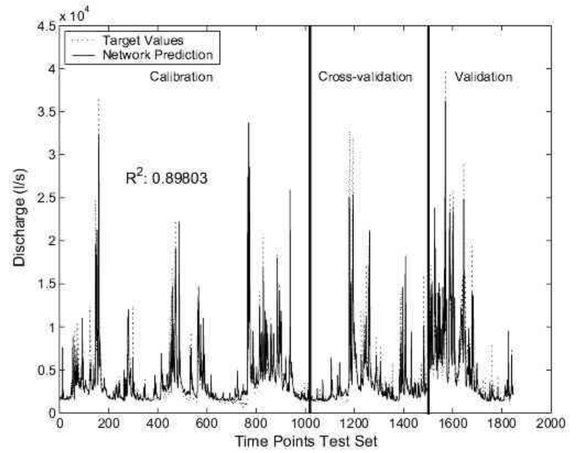


Figure 3. Simulation results over complete data period (1996-2001); forecast lead time equal to zero

Results

The low time resolution of the data (days), considering the size of the catchment and the time scales of the dominant runoff processes, constrained the forecasting capability of our models.

Figure 3 shows the results of a simulation over the entire length of the time series, in which the current discharge is simulated using current and previous rainfall and evaporation values, and previous values of the discharge. This is the ideal case in which the forecast lead time is zero.

Table 2 shows the mean performance (over 10 runs) of various ANN model types for a one-day-ahead forecast of Q. Figs 4 and 5 show the best results of model structures 2 and 3. Model structure 2 performs much better than model structure 1: the groundwater level information represents the hydrological state well.

Table 2. Mean performance of various ANN model structures for one-day-ahead forecast of Q

	ANN Inputs		Performance	
	Variables	Window of time	RMSE	R^2
1	P E	t-6 to t0 t-4 to t0	4450	0.277
2	P E GW	t-6 to t0 t-4 to t0 t-6 to t0	3350	0.582
3	P E Q	t-6 to t0 t-4 to t0 t-2 to t0	3120	0.631
4	P E Q GW	t-6 to t0 t-4 to t0 t-2 to t0 t-6 to t0	3070	0.655

P = precipitation;
E = evaporation;
GW = groundwater level;
Q = discharge;
RMSE = Root Mean Squared Error;
R2 = Nash Sutcliffe coefficient.

The performance of model structure 3 shows that using previous discharge values is an even better way of representing hydrological state. Combining both state indicators (model structure 4) results in a minor performance gain: there is considerable information overlap.

Conclusion

ANNs are capable of modelling the transformation between rainfall and runoff. However, the time resolution of the available data was too low (in proportion to the average lag time between peak rainfall and peak discharge) for the forecast performance to be very good. Groundwater level information may be successfully used as additional ANN model input for rainfall-runoff simulation. It is a good indicator of the hydrological state of the catchment.

References

ASCE Task Committee on Application of Artificial Neural Networks in Hydrology, 2000. Artificial neural networks in hydrology, II: hydrologic applications. Journal of Hydrologic Engineering 5(2), pp.124-137.

Beven, K.J., 2001. How far can we go in distributed hydrological modelling? Hydrology and Earth System Sciences 5(1), pp. 1-12.

Hsu, K.L., H.V. Gupta, & S. Sorooshian, 1995. Artificial neural network modeling of the rainfall-runoff process. Water Resources Research 31(10), pp. 2517-2530.

Rajurkar, M.P., U.C. Kothyari, & U.C. Chaube, 2004. Modeling of the daily rainfall-runoff relationship with artificial neural network. Journal of Hydrology 285, pp. 96-113.

Shamseldin, A.Y., 1997. Application of a neural network technique to rainfall-runoff modelling. Journal of Hydrology 199, pp. 272-294.

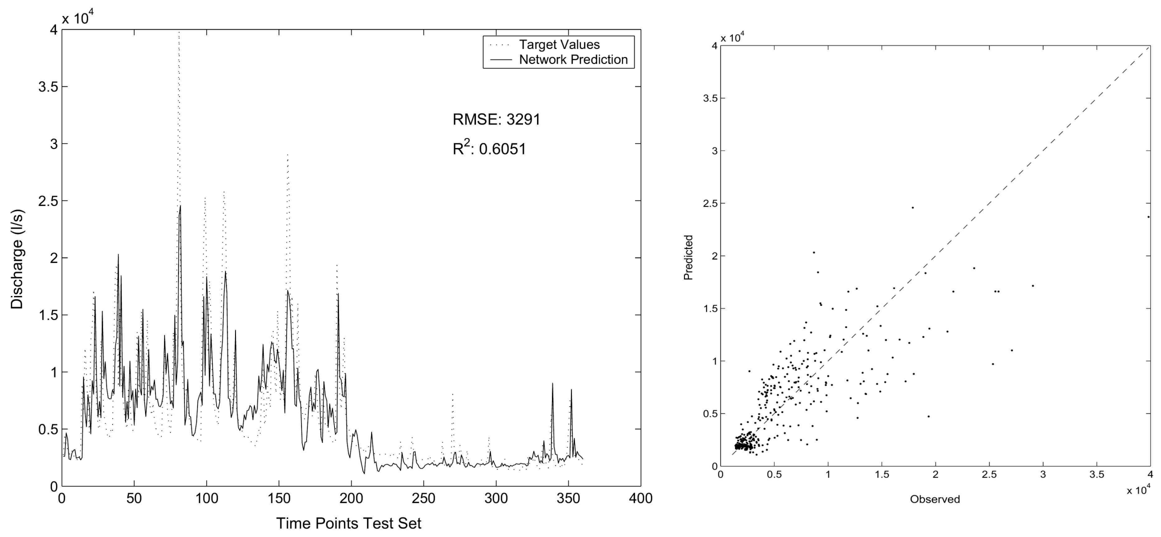


Figure 4. Model structure 2 forecasting results over validation period (groundwater levels as state indicator)

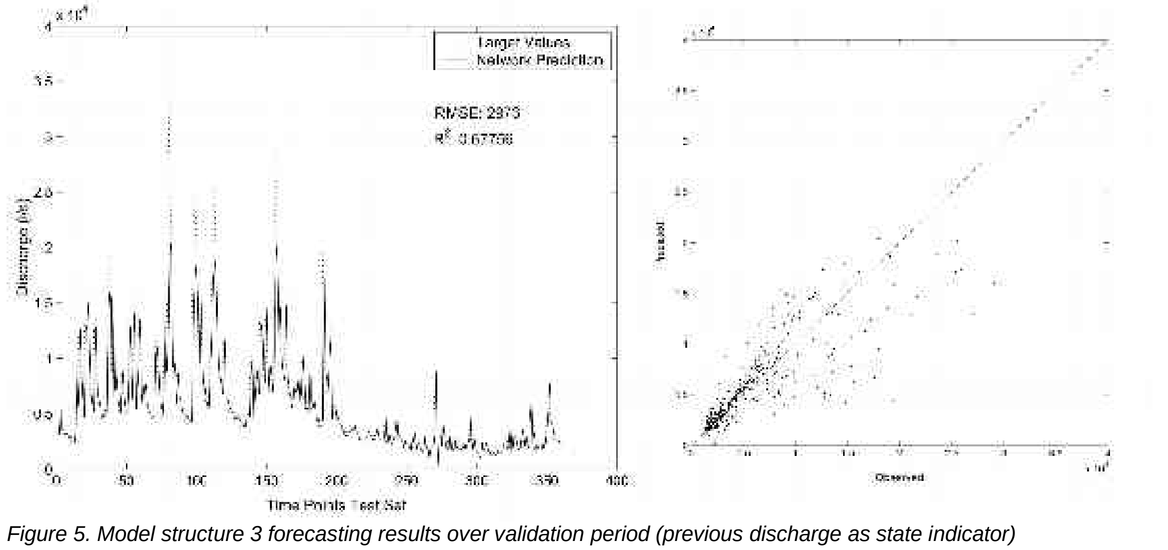


Figure 5. Model structure 3 forecasting results over validation period (previous discharge as state indicator)

Implications of hydrological modelling and observations in the Alzette river basin

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Introduction

Physically based rainfall-runoff models have been evolved remarkably over the past decades along with recognition and descriptions of different runoff processes. Infiltration excess overland flow and saturation overland flow are two major runoff generation mechanisms that are widely adopted in model approaches, e.g. REW approach (Reggiani et al., 1999, 2000, Reggiani & Rientjes, 2005; Zhang et al., 2003, in press). However, subsurface storm flow processes, such as macropore flow, preferential flow and pipe flow, generally are not well addressed in those model approaches, even though they have been extensively investigated (e.g. Uhlenbrook et al., 2002).

In this study, we applied the REW approach to a sub-catchment of the Alzette river basin in Luxembourg. Modelling results showed that stream hydrographs are generally well simulated.

However, the simulated saturation overland flow area fractions for most of the REWs (sub-watersheds) are relatively large compared to the values reported in the research for other catchments. Through analyzing the modelling results, re-examining the model structure and evaluating the field observations, we conclude that quick subsurface flow processes are dominant in the Alzette river basin and should be further investigated. Therefore, a quick subsurface flow component should be taken into account in the model code to improve the representation of not only the stream hydrograph, but also the other state variables, such as groundwater level and saturated area fractions.

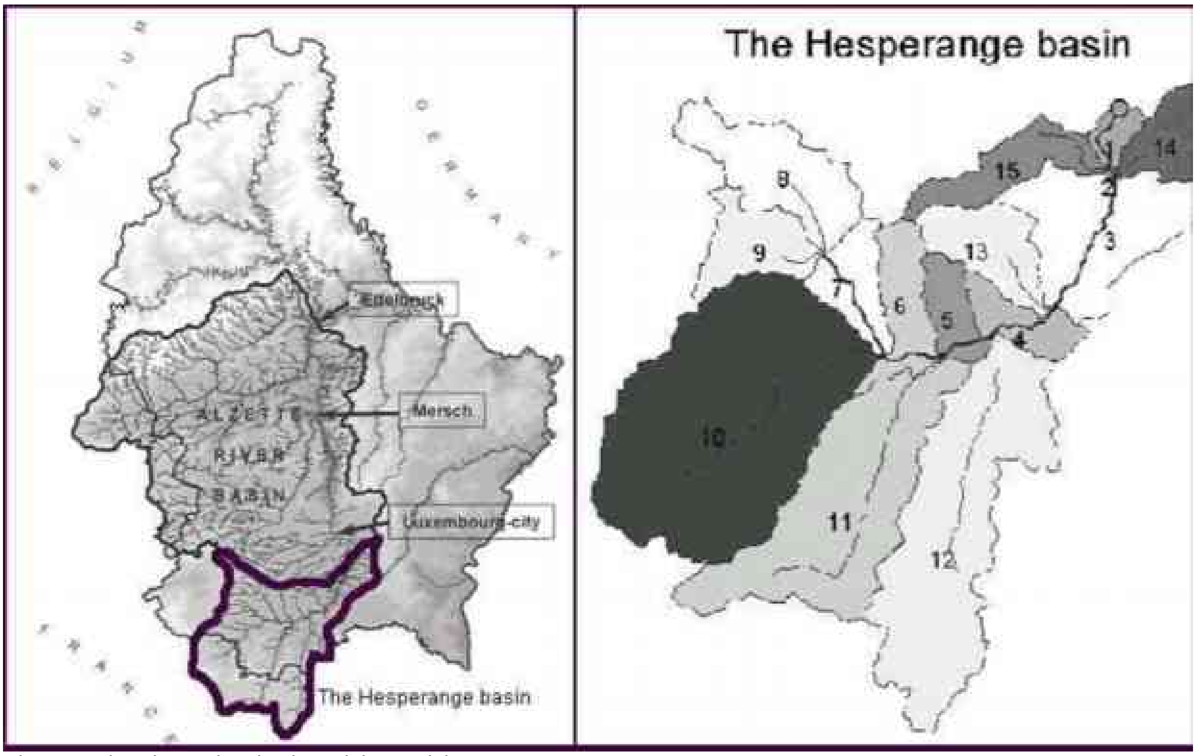

Figure 1. The Alzette river basin and the model area

Modelling watershed response in the Alzette basin

The Representative Elementary Watershed (REW) approach is applied to set up the model to simulate the watershed response to rainfall events. Using physically based ordinary differential equations, the model describes the most dominant hydrological processes, *i.e.* saturation overland flow, unsaturated subsurface flow, saturated groundwater flow and river channel flow. In addition, interception and groundwater outflow are taken into account.

The Alzette river basin (Fig.1) is mainly located in the Luxembourg part of the Paris geological basin. The Hesperange sub-basin (Fig. 1), for which the rainfall-runoff model has been built, is selected for this study. Since the beginning of the 1990's, a dense hydro-climatological observation network has been established in the Alzette basin (Pfister & Hoffmann, 2002).

Numerical simulations

The Hesperange sub-basin is divided into 15 REWs (Fig. 1) using the 3rd order threshold of the Strahler order system. Runoff simulations are carried out using daily rainfall and potential evaporation time series as external driving force. The simulation period is from 01/01/1998 to 12/31/1998. Initial conditions (e.g. soil moisture content) and soil parameters are set to uniformly distributed over each REW. Geometric properties of each REW are derived from the DEM data. For brevity, we only present here the modelling results of the stream hydrograph at the outlet of the Hesperange sub-basin (Fig. 2) and the saturation overland flow area fraction for each REW (Fig. 3).

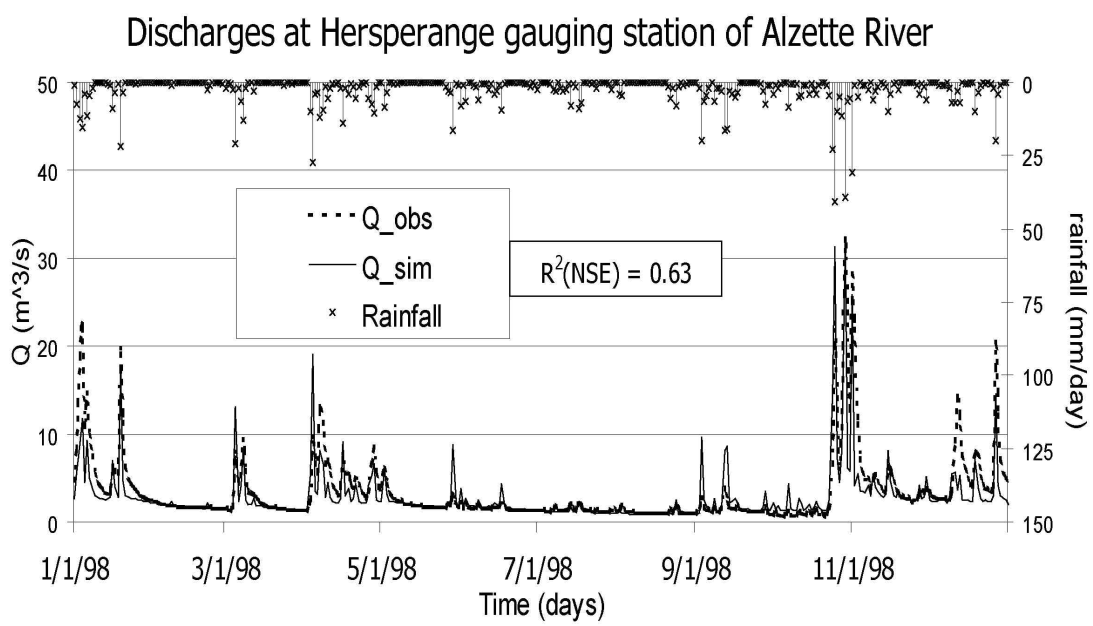

Figure 2. Simulated and measured discharges

Discussion and conclusions

- The general dynamics of the watershed responses, represented by the discharge at the outlet, is well simulated (Fig. 2).
- Topographic control on the saturated area formation is well represented by the model: the steeper the hillslope, the smaller the saturated area (Fig. 3), and vice versa.
- Recession limbs for some of the peak discharge events are less well modelled since the current model is lacking a mechanism to describe this hydrological response.
- The simulated saturated area fractions for many of the REWs are relatively high. This is due to the fact that the saturation overland flow is the only mechanism in the current model to represent all quick flow components. Thus, a relatively large saturated area is needed to support the storm runoff generation in order to reproduce the stream hydrograph.
- Field observations in the study area indicate that saturated areas are rather localized and concentrated in the valleys. It also has been noticed that macropores in soils and fractures in weathered rocks are existing. Therefore, quick subsurface

flow processes are likely to be dominant in this basin.

- The REW approach and the model applied here are capable of describing a meso-scale watershed rainfall runoff relation. However, the model structure needs to be improved when applied to a catchment like the Alzette river basin where subsurface storm flow processes prevail.

Acknowledgement
This research is funded by Delft Cluster project ‘Oppervlakte water hydrologie’.

References
Pfister, L. & L. Hoffmann, 2002. Experimental hydro-climatological atlas of the Alzette river basin - Grand-duchy of Luxembourg. Centre de Recherche Rublic - Gabriel Lippmann, Cellule de Recherche en Environnement et Biotechnologies, Luxembourg.
Reggiani, P., S.M. Hassanizadeh, M. Sivapalan & W.G. Gray, 1999. A unifying framework of watershed thermodynamics: constitutive relationships. Advances in Water Resources, 23(1), pp. 15-39.
Reggiani, P., M. Sivapalan & S.M. Hassanizadeh, 2000. Conservation equations governing hillslope responses: physical basis of water balance. Water Resources Research, 36(7), pp. 1845-1863.
Reggiani P. & T.H.M. Rientjes, 2005. Flux parameterization in the representative elementary watershed approach: application to a natural basin. Water Resources Research 41 (4), W04014.
Uhlenbrook, S., M. Frey, C. Leibundgut, & P. Maloszwski, 2002. Hydrograph separations in a mesoscale mountainous basin at event and seasonal timescales. Water Resources Research, 38(6), pp. 1-14.
Zhang G., P. Reggiani, T.H.M. Rientjes & S.M. Hassanizadeh, 2003. Modeling rainfall-runoff relation by Representative Elementary Watershed approach. In: R.S.E.W. Leuven, A.G. van Os, & P.H. Nienhuis (eds.), Proceedings of NCR-days 2002; current themes in Dutch river research, NCR-publication 20-2003.
Netherlands Centre for River Studies, Delft, pp. 20-22.
Zhang G.P., F. Fenicia, T.H.M. Rientjes, P. Reggiani & H.H.G. Savenije, in press. Modeling runoff generation in the Geer river catchment with improved model parameterization to the REW approach. Physics and Chemistry of the Earth.

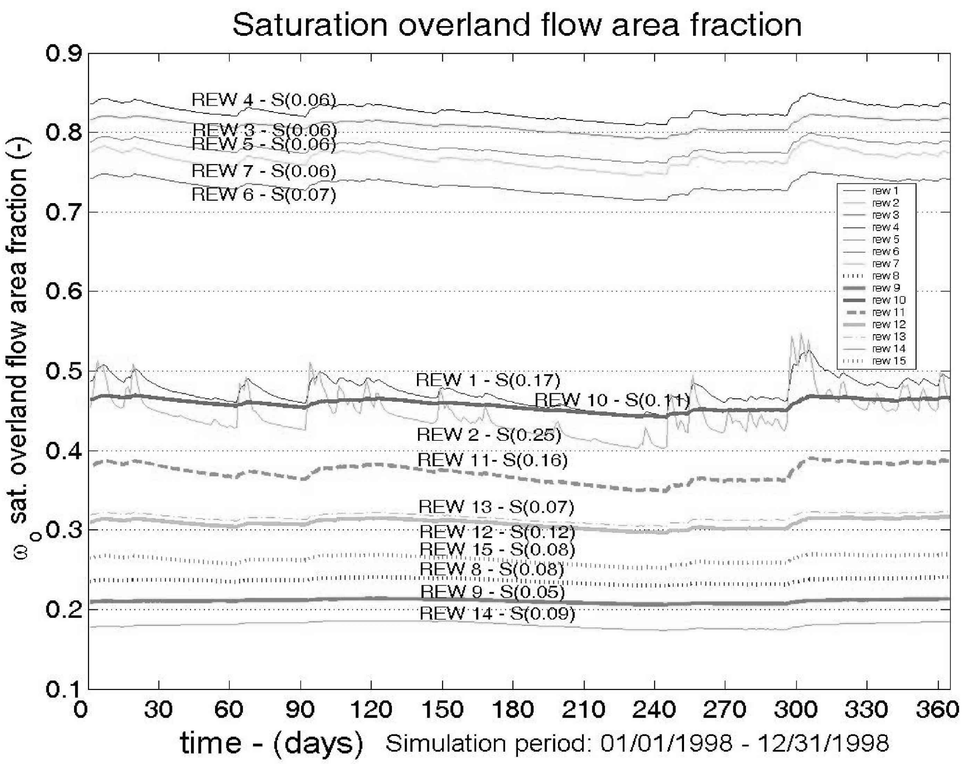

Figure 3. Simulated saturation overland flow area fraction

Surface water management during droughts in peat areas

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Introduction

During the dry summer of 2003, surface water was added to peat areas to prevent decreasing water table levels and oxidation of the peat. Great efforts have to be made to ensure these high water levels, however, effectiveness of high surface water levels during dry summers is doubtful. To understand water flow patterns and flow directions within peat soils, we combined field measurements with model results. As a result, key parameters that influence the interaction between surface water level and groundwater level were found.

Methods

We selected three field sites to monitor surface water levels, groundwater levels and groundwater quality. (De Meije, Vlietpolder and Ilperveld). Each site has its own local hydrology (e.g. Fig. 1), which determines water flow directions.

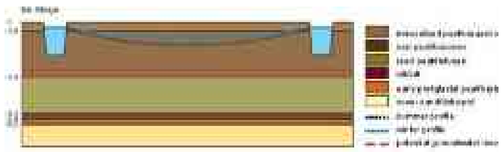

Figure 1. Schematic overview of subsurface lithology and groundwater levels in De Meije.

Important differences between sites are the amount of infiltration, compaction of the peat and vegetation. De Meije and Ilperveld are nature conservation areas (with very loose peat structures and therefore high hydraulic conductivities), whereas the Vlietpolder is an agricultural site. In this paper, the field measurements and model results of De Meije are presented and discussed.

Measurements

Time series of groundwater levels in De Meije show that the effect of surface water level change on the groundwater levels strongly depends on the ditch density. Making use of a long 'prikstok', cross-sections of winter and summer electrical conductivity (EC) and temperature (Fig. 2) have been measured between two ditches. The ditches contain high (120 mg/l) chloride concentrations during summer and low concentrations (15 mg/l) during winter. The temperature cross-sections for summer and winter are fairly symmetrical as expected. A high temperature during summer in the center of the field might be caused by preferential flow. The Ec cross-sections correspond well to the temperature profiles. In summer it shows the same fast downward flow in the center of the profile.

From these measured profiles we can conclude that in De Meije preferential flow is an important process. Mechanisms that cause this preferential flow, like compaction from the top, change of hydraulic conductivity related to inward flux from ditches, or influence of vegetation, are still unknown.

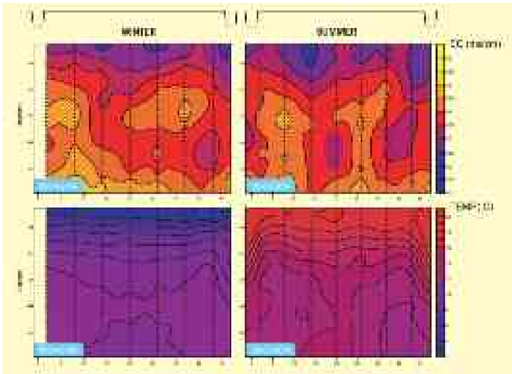

Figure 2. Winter and summer profiles of soil electrical conductivity (EC; upper graphs) and winter and summer profiles of soil temperature (TEMP; lower graphs).

Models

A modflow model study has been conducted of the impact of lowering the surface water level under natural evaporation of 40 cm in 2 months. Figure 3 shows a sample result for De Meije. In the summer months (between day 160 and day 255, x-axis) the surface water level decreased by 40 cm. The figure shows the drawdown (expressed with a color scale) in the meadow (Y-axis represents distance from ditch) resulting from a decreasing surface water level in summer.

Hydrus 2-D has been used to understand the flow patterns within the field cross-section of De Meije. The ditches contain high (120 mg/l) chloride concentrations during summer and low concentrations (15 mg/l) during winter. The water level of the ditches was kept constant during simulations. The main overall flow direction is downward, but close to the ditches the main flow direction is horizontal (more so in summer than in winter due to evapotranspiration). This process is creating 'bananas', zones with relatively high chloride concentrations (Fig. 4).

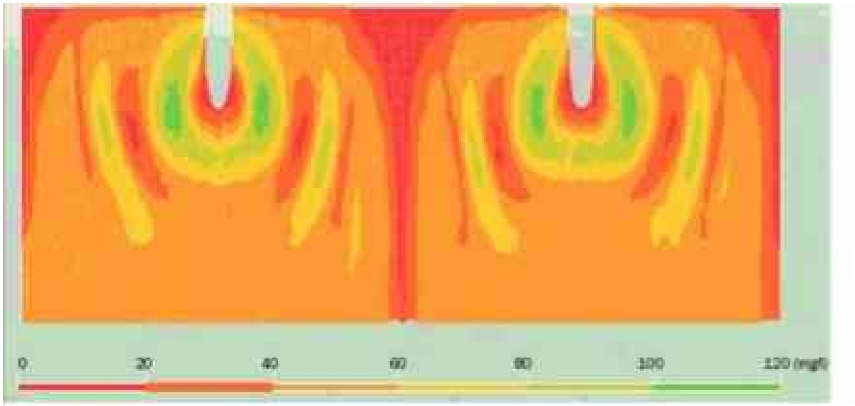

Figure 4. Hydrus 2-D calculation of concentration patterns in winter within a cross-section (40 m)

Model results do not clearly resemble the measurements of EC profiles in De Meije, but could explain the large variety in areas with low and high concentrations observed.

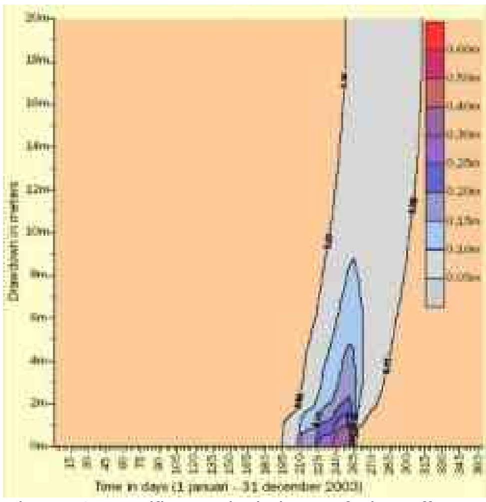

Figure 3. Modflow calculations of the effect of lowering the surface water level by 40 cm during a dry summer.

Conclusions

Key parameters influencing interaction between surface water level and groundwater level are: (1) ditch density and (2) the local hydrology. The measured EC-profiles do not match the Hydrus model results. Thus, unknown factors influence water flow patterns, like heterogeneity of the subsurface and soil properties.

Future work

- Continuing fieldwork on groundwater quality to understand flow patterns.
- More research on heterogeneity and physics of peat soil properties and surface water sediment resistivity.
- Production of a sensitivity map (i.e. a map with peat areas sensitive to surface water level changes during dry summers).

Development of nutrient loads from headwaters to lowland rivers

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Abstract
Eutrophication problems in shallow water bodies triggered the development of large (drainage basin) scale models to simulate the origin, transfer and retention of nutrients. Although these models are well capable of simulating long-term average nutrient loads, the spatial and temporal distribution of transfer and retention processes is still unknown. Therefore, we took water quality samples, and measured discharges at 80-100 locations in a 900 km^2 catchment in Estonia during six field campaigns. Samples were taken from tile drains, sources, and lower and higher order streams. First results for nitrate show the importance of seasonality, land cover, hydrological connectivity, and in-stream retention for the development of nutrient loads. We will use this information to improve process descriptions in large-scale models.

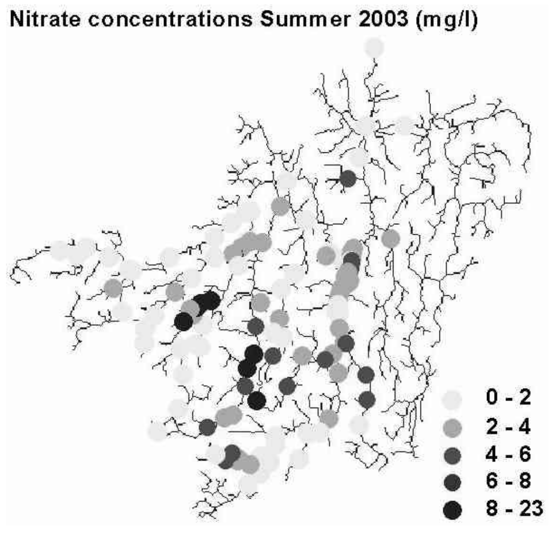

Figure 1. Nitrate concentrations in summer 2003

Introduction
Eutrophication of shallow water bodies by elevated nutrient concentrations is one of the most common environmental problems. The input of nutrients is a complex function of nutrient emissions, their transfer through various hydrological pathways, temporary storage and decay in soil and groundwater, and retention processes in the drainage basin. De Wit (2001) and Mourad et al. (2005) have proved that it is well possible to model long-term average nutrient fluxes within a drainage basin, using large, easily to obtain GIS datasets. Fluxes are simulated on basis of relatively easy to obtain statistical data about point and diffuse emissions, and maps with land cover, elevation, drainage network, hydrological fluxes and residence times. However, the spatial and temporal distribution of processes that dominate the transfer of nutrients from the land surface to the river outlet are still unknown, because the models are usually calibrated only on average nutrient loads from a limited amount of river locations. Only when the spatial and temporal distribution of nutrient concentrations and loads at the medium (catchment) scale (100-1000 km^2) is known, we can improve process descriptions in drainage basin scale models and make them suitable for the evaluation of mitigation measures to prevent excessive nutrient loads.

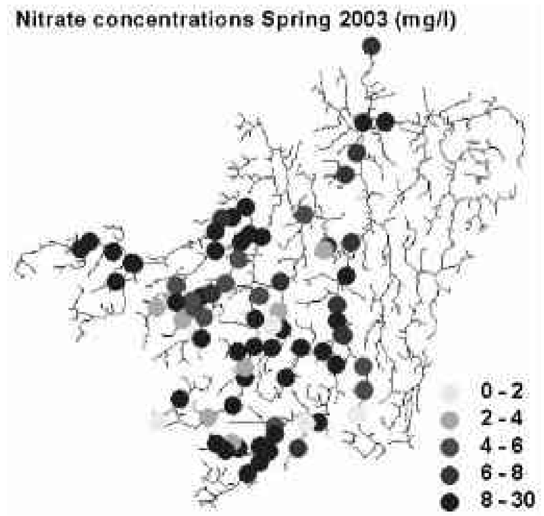

Figure 2. Nitrate concentrations in spring 2003

Methods
We carried out six field campaigns in the lowland catchment of the Ahja jõgi in Estonia (area: 900 km^2), which is characterized by alternating agricultural areas and forests and peat bogs. Higher order rivers are typically situated in wide semi-natural valleys filled with

riparian wetlands and surrounded by forested slopes. The lower order streams often have a more direct connection to the agricultural fields. There is one town in the catchment, Põlva (6500 inhabitants). During six field campaigns (Summer 2002; Autumn 2002, Spring 2003, Summer 2003, Autumn 2004, Spring 2004), water samples were taken at approximately 80-100 different locations spread over the catchment. These locations are covering streams of all sizes and types, including tile drains, sources and first order streams as well as higher order rivers. Additionally, we estimated stream discharge where possible. The water samples were analyzed for the major water quality ions in the Laboratory of Physical Geography, Utrecht University. Concentrations (mg l^{-1}) of the main nutrient species NH_4^+, NO_3^-, and PO_4^{3+} were plot as maps and river profiles for all field campaigns. Discharge measurements were used to calculate average daily loads (kg d^{-1}) for the sampling periods. Here we restrict ourselves to nitrate (NO_3^-).

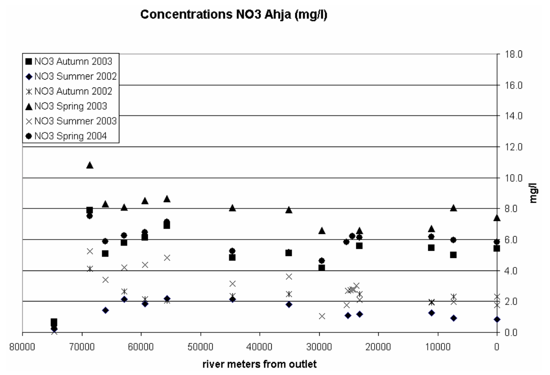

Figure 3. Nitrate concentrations profile of the Ahja jõgi river for the six seasons

Results

Figure 1 shows the spatial distribution of nitrate concentrations during summer baseflow conditions. High nitrate concentrations are found downstream of wastewater outlets, and in agricultural areas where fields are directly connected to streams. Further downstream, concentrations tend to decrease. However, during spring flood, high nitrate concentrations are present almost everywhere (Fig. 2), in both lower and higher order streams. The nitrate concentration profile for the Ahja jõgi (Fig. 3) shows that concentrations in spring 2003 are the highest (around 7-8 mg l^{-1}), followed by concentrations in spring 2004 and autumn 2003 (4-6.5 mg l^{-1}).

Concentrations in summer 2002, summer 2003 and autumn 2002 (all baseflow periods) are typically 1-5 mg 1^{-1}. The daily load profile of the Ahja jõgi (figure 4) shows even more difference between the seasons. Note that loads quickly increase in downstream direction during spring 2003, and to a lesser extent during spring 2004 and autumn 2003. Retention inhibits a downstream increase of loads during baseflow periods. Loads, mainly developing upstream, do not increase further downstream.

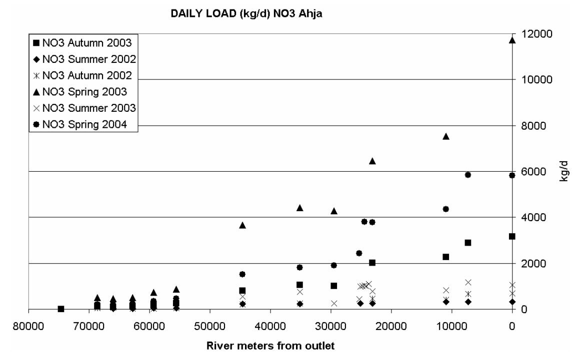

Figure 4. Nitrate loads profile of the Ahja jõgi river for the six seasons

Conclusions and outlook

The first results reveal that there is a strong seasonal variation in nitrate concentrations and loads, caused by both higher concentrations and higher discharges in the winter half year. The spatial variation in nitrate concentrations and loads in the catchment roughly follows land cover: In agricultural areas and near point emissions, concentrations and loads are higher than in forested areas. Moreover, the connectivity of the hydrological pathways from field to stream is important. In (summer) baseflow periods, nitrate export is limited by retention in bed sediments, which seems absent during spring flood. For the improvement of drainage basin scale models, we will focus on seasonality and hydrological connectivity.

References

De Wit, M.J.M., 2001. Nutrient fluxes at the river basin scale. I: the PolFlow model. Hydrological Processes 15, pp. 743-759.

Mourad, D.S.J., M. van der Perk, G.D. Gooch, E. Loigu, K. Piirimäe, & P. Stålnacke, 2005. GIS-based quantification of future nutrient loads into Lake Peipsi / Chudskoe using qualitative regional development scenarios. Water Science and Technology 51(3-4), pp. 355-363

Floodplain sedimentation regulating vegetation productivity on small rivers?

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Abstract
Sediment input and associated nutrients were quantified along a vegetation gradient from the river channel to the floodplain margin in five nature reserves on four small rivers. The amount of sedimentation during the flood season of 2003-2004 was measured using sediment traps. Grain-size and nutrient analyses of the trapped sediment samples were carried out. The biomass of the vegetation is different for all investigated areas and varies between 900 g/m^2 and 200 g/m^2. Especially in the Kapperbult area on the Drentsche Aa, the biomass decreases with increasing distance from the river. Measured amounts of sediment in the Kapperbult area are small and strongly decrease with increasing distance from the river: 2.7 kg/m^2 close to the river and 0-0.07 kg/m^2 far from the river. Likewise, nitrogen and phosphate input through sedimentation also decrease with increasing distance.

Figure 1. Location of the study sites

Introduction
Flooding or water retention in combination with nature development is not in all situations without risk for the vegetation (Commissie Waterbeheer 21e eeuw, 2000; Raad voor het Landelijk Gebied, 2001). Especially vegetation in nutrient-poor conditions will have considerable harm from flooding with nutrient-rich water. The hypothesis is that differences in biomass productivity are explained by differences in sedimentation. Quantitatively, however, the input of nutrients like nitrogen and phosphate by flooding is largely unknown (Sival et al., 2002).

The main question in our research is: what is the relationship between input of nutrients by sedimentation and the productivity for different vegetations along a gradient from the river to the floodplain margin? Is the input from sediments comparable to the input from floodwater, atmospheric deposition, mineralization and groundwater? We investigated five nature reserves on four small rivers in the Netherlands (Dommel, Drentsche Aa, Reest and Overijsselse Vecht; Fig. 1). In this paper we will mainly present results from the Kapperbult area on the Drentsche Aa.

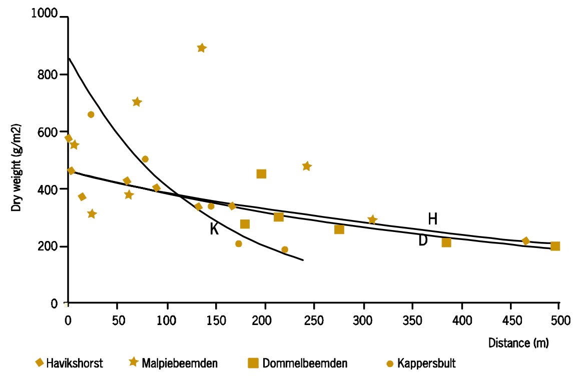

Figure 2. Vegetation biomass (g/m^2) along a gradient from the river to the floodplain margin of all investigated sites

Methods
To characterize the soil and vegetation, an inventory of both was included in the research. The standing crop of the vegetation was measured in the summer by cutting the vegetation. After drying, the vegetation sample was weighed and analyzed on N and P. Sediment traps were placed along vegetation gradients across the levee and floodbasin to the floodplain margin, in each of the study areas. After flooding, the traps were collected and the trapped sediment was analyzed on: (1) quantity, (2) texture, (3) N and P content. Special attention was paid to spatial patterns of these variables in relation to floodplain geomorphology.

Results
The biomass of the vegetation is different for all investigated areas and varies between 900

g/m^2 and 200 g/m^2 (Fig. 2). With increasing distance from the river the biomass decreases and this effect is most pronounced in the Kappersbult area on the Drentsche Aa. Low-productive vegetation (<400g/m^2), assumed to be most sensitive to nutrient input by flooding, is present far from the river.

A borehole cross-section at the Kappersbult reveals an approximately 60-cm-thick clayey and peaty clay bed on underlying peat that fills the deep Drentsche Aa palaeovalley (Fig. 3). Further away from the Drentsche Aa the clayey bed rests on fine (loamy) sand representing a coversand ridge bordering the palaeovalley. These subsurface data suggest a recent increase in sediment input, although the absolute date of this change is unknown. The composition of the topsoil reflects the present sedimentary processes. The impact of sedimentation history (and the resulting spatial variation in subsurface composition) on present vegetation productivity is still under study.

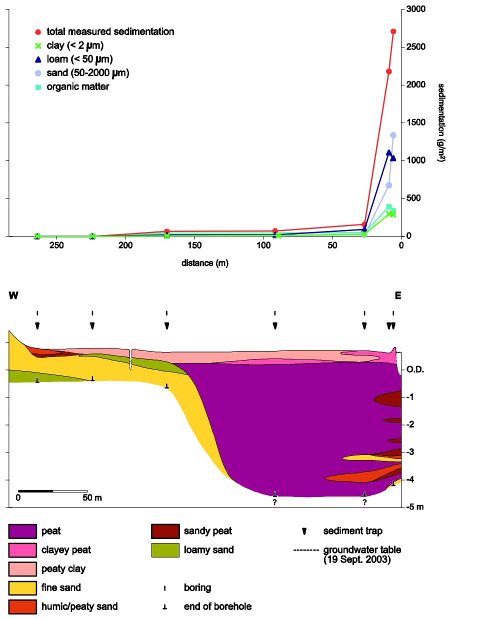

Figure 3. Measured sedimentation and the corresponding lithological borehole cross-section in the Kappersbult area

In January 2004, most study areas were flooded, with a maximum flooding duration of one week. The amounts of sediment deposited in the Kappersbult area strongly decrease with increasing distance from the river: 2.7 kg/m^2 close to the river and 0-0.07 kg/m^2 far from the river. Absolute amounts of deposited clay and organic matter, although being much lower, show a comparable spatial trend. Nitrogen and phosphate amounts also decrease with increasing distance from the river (Fig. 4). Nitrogen input varies between 90 kg/ha close to the river and 5 kg/ha far from the river (for obtaining an estimate of total input, an atmospheric deposition of 30 kg/h must be added). Phosphate input varies between 45 kg/ha close to the river and 1 kg/ha far from the river.

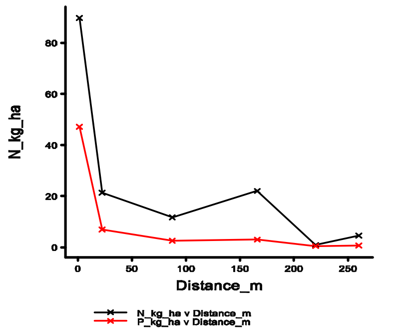

Figure 4. Amount of sediment input of nitrogen (N) and phosphate (P) (kg/ha) along a gradient from the river to the floodplain margin in the Kappersbult area

Conclusions

In the Kappersbult area the textural composition of the sediments that are presently being deposited, matches the composition of the topsoil, indicating no recent changes in the sedimentary processes. In this area the biomass of the vegetation seems to depend on the nutrient input from sediments: both significantly decrease with increasing distance from the river. These results suggest that increasing sedimentation, associated with increased flooding/water retention, may cause a change from low-productive floodplain grassland into high-productive floodplain grassland. Generally, this process will involve a strong decrease in the amount of species present in the vegetation.

Acknowledgements

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References

Commissie Waterbeheer 21e eeuw, 2000. Waterbeleid voor de 21ste eeuw. Advies van de commissie Waterbeheer 21ste eeuw. Den Haag, 54 p.

Raad voor het Landelijk Gebied, 2001. Bergen met beleid. Publicatie 01/4, Raad voor het Landelijk Gebied, Amersfoort, 48 p.

Sival, F.P., P.C. Jansen, B.S.J. Nijhof & A.H. Heidema, 2002. Overstroming en vegetatie: literatuurstudie over de effecten van overstroming op zuurgraad en voedselrijkdom. Alterra-rapport 335, Alterra, Wageningen, 66 p

Ecological impact of changes in groundwater withdrawal in river forelands

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Abstract
The project 'Buurtschap IJsselzone' is an initiative for rural development along the river IJssel at Zwolle, The Netherlands. One of the objectives of the project is to secure the present drinking water supply by the reallocation of abstraction wells of the drinking water production station Engelse Werk. The model NICHE was used to gain insight in the ecological effects of the reallocation of abstraction wells in the floodplains of the IJssel. Model output showed that not only river water dynamics affects habitats of plant- and birdlife directly, but groundwater hydrology as well. The results of the assessment led to an alternative design of abstraction wells, which forms a sound basis for nature development in the floodplain area.

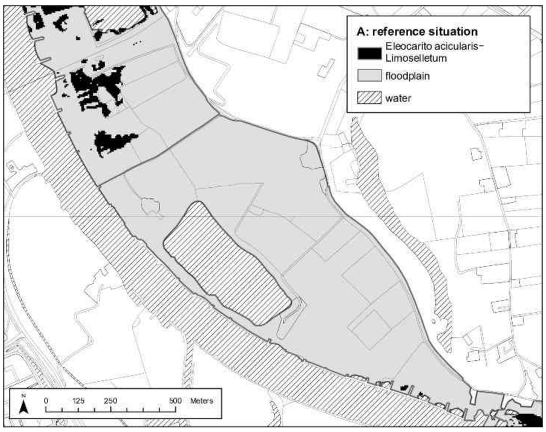

Figure 1. Predicted vegetation patterns of Eleocharito acicularis-Limoselletum in the floodplain Schellerwaarden. A: reference situation, with nature development in current agricultural land.

Introduction
The study area 'Buurtschap IJsselzone' is situated between the city of Zwolle and the river IJssel, which is a distributary of the Rhine. River forelands (embanked floodplains) form a major part of the study area and consist mainly of nature reserves and agricultural meadows.

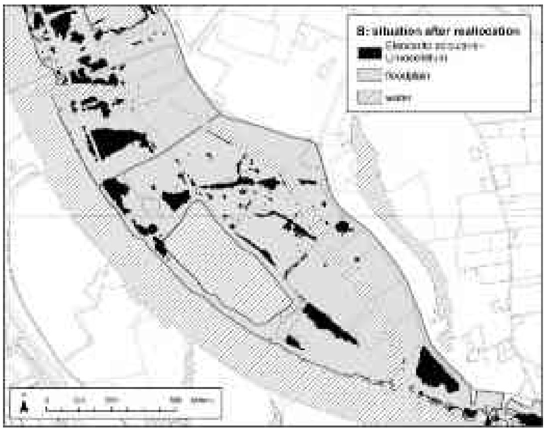

Figure 1. Predicted vegetation patterns of Eleocharito acicularis-Limoselletum in the floodplain Schellerwaarden. B: situation after reallocation of drinking water abstraction, with a new river side-channel and nature development.

In the study area several major issues related to spatial planning exist. In the river forelands, more storage capacity for river water is required during periods of peak discharge of the Rhine. This area is also protected by the European Bird Directive and is part of the national ecological network of the Netherlands. Pollution of groundwater under the city of Zwolle and the construction of a new railway threaten the present drinking water production station Engelse Werk, and a new design of abstraction wells is required to prevent further increase of treatment costs. Furthermore, social-economical functions such as agriculture are declining. In order to combine these issues in a multifunctional landscape, an initiative for rural development in the 'Buurtschap IJsselzone' was started (De Kuijer et al., 2003).

For the objective to realise a sustainable drinking water production without risks of contamination by pollution, a sustainable development of the catchment area is necessary.

Plans for reallocation of the present groundwater abstraction by the drinking water company Vitens are therefore interwoven with the initiative for rural development. Supplementary values for Vitens are the realisation of a social basis for water production and the prevention of a governmental deadlock over the socio-economical development and spatial planning. Since changes in groundwater abstraction may affect nature and environment, a detailed environmental impact assessment of reallocation is required. This contribution focuses on the assessment of the reallocation of abstraction wells on the occurrence of vegetation and bird communities in the river forelands.

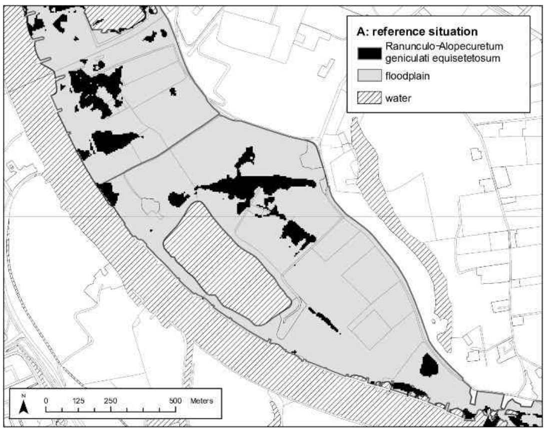

Figure 2. Predicted vegetation patterns of Ranunculo-Alopecuretum geniculati equisetetosum palustris in the floodplain Schellerwaarden. A: reference situation, with nature development in current agricultural land.

Ecological impact assessment

The river forelands in the study area contain important ecological values. Ecological effects are expected on a small scale (< 1 ha) and may interfere with nature restoration projects. This requires an ecological impact assessment method with high accuracy on this scale. The method needs to calculate effects of changes in groundwater level, changes in surface water dynamics as well as changes in land use on distribution patterns of plant communities and ecological groups of breeding birds. The scale of this output corresponds with the information that is needed in the planning and control of nature management.

Aggenbach & Pelsma (in prep.) constructed a database (PREVIEW) with site conditions of plant communities of river forelands. From this database, parameters concerning inundation with river water, groundwater level, soil characteristics and management were taken into account. Most data could be derived from available hydrological and soil information. In order to use the model in river forelands, a calculation of inundation depth and inundation duration throughout spring and summer was carried out by Blonk (2003). From these data, the site conditions acidity and trophic state were calculated with the model NICHE (Raterman et al., 2002).

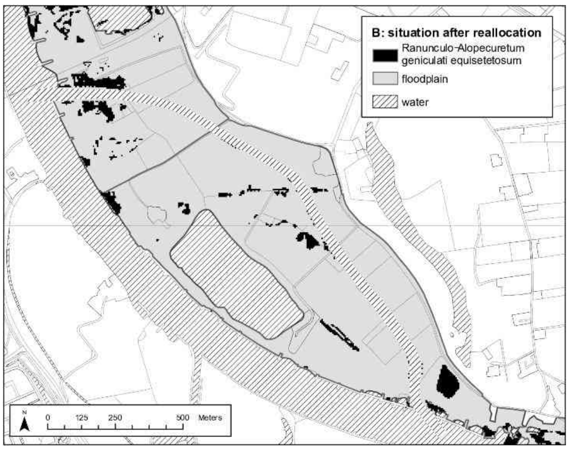

Figure 2. Predicted vegetation patterns of Ranunculo-Alopecuretum geniculati equisetetosum palustris in the floodplain Schellerwaarden. B: situation after reallocation of drinking water abstraction, with a new river side-channel and nature development.

The model used the calculated site conditions to predict the potential occurrence of plant communities. In order to generate information about the habitat suitability for breeding birds, these results were combined with information about landscape structure and disturbing factors such as infrastructure. An avifauna-database (Sierdsema, 1995) was used to translate these habitat factors to patterns of ecological bird communities.

Results

Although several alternatives for reallocation of the drinking water abstraction were studied, only the results of the final most-environmental-friendly alternative will be discussed. In this alternative, hydrological effects of the reallocation are restricted to the river foreland currently in use for agriculture. In order to protect present nature reserves, the catchment area of the groundwater extraction station was reduced by proposing a river side-channel in the agricultural floodplain.

Important hydrological parameters that changed due to reallocation were inundation duration with river water and lowest groundwater tables. Due to the planned river side-channel, the river water will flow freely into the floodplain. As a consequence low-lying areas will be flooded easily. On the other hand, the groundwater table will decrease due to the reallocation of abstraction wells.

According to the model output, the effects of these two hydrological changes on vegetation patterns appear to be very different. This is illustrated by the patterns of the pioneer vegetation Eleocharito-Limoselletum and the grassland vegetation Ranunculo-Alopecuretum equisetetosum (Figs 1 and 2). Both plant communities occur in the low parts of river forelands, often adjacent to each other. However, in the study area the Eleocharito-Limoselletum showed a positive reaction to increased inundation, whereas the Ranunculo-Alopecuretum equisetetosum showed a negative reaction to decreased groundwater tables. The model also calculated a different reaction of breeding birds to the hydrological changes. Habitats of typical meadow birds with ground nests will decrease because of the increased inundation duration, whereas habitats of marshland birds will move towards zones along the planned river side-channel.

Conclusions

The model output showed that not only the dynamics of inundation by river water affect habitats of plant life and birdlife in river forelands, but groundwater hydrology as well. Relative small changes in groundwater level in floodplains already affect plant communities restricted to continuous high summer water tables. Since the required site conditions of plant communities show great differences, and small changes in abiotic conditions may cause major changes in distribution patterns of valuable plant communities, ecological assessment of hydrological impacts in river forelands requires a model that distinguishes vegetation types on community level.

The results of the ecological impact assessment in the project ‘Buurtschap IJsselzone’ led to an alternative design of abstraction wells, which forms a sound basis for nature development in the floodplain area. The planned construction of a river side-channel will restrict effects of groundwater abstraction to parts of the river foreland in agricultural use. At the same time, the construction of a river side-channel opens up new perspectives for nature development. The model-instrument appeared to be helpful in further spatial planning of rural development in the study area.

References

Aggenbach, C.J.S. & T.A.H.M. Pelsma, in press. Hydro-ecological assessment of vegetation of Dutch river habitats. Archiv für Hydrobiologie Suppl. Large Rivers.

Blonk, A.T., 2003. Bouw instationair grondwatermodel “Engelse Werk”. Tauw BV, Deventer.

De Kuijer, O., A.J.M. Jansen & H. de Graaf, 2003. Buurtschap IJsselzone biedt meervoudig perspectief. Nova Terra 3 (2), pp. 14-19.

Raterman, B.W., M.W.A. de Haan, & A.F.M. Meuleman, 2002. GIS in ecological impact assessment of wetlands. ESRI User conference proceedings 2002 (http://gis.esri.com/library/userconf/proc02/abstracts/a0622.html).

Sierdsema, H., 1995. Broedvogels en beheer: het gebruik van broedvogelgegevens in het beheer van bos- en natuurterreinen. SBB/SOVON, Driebergen/Beek-Ubbergen.

Cumulative effect assessment of physical reconstruction and land-use changes on riverine biodiversity

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Abstract
A GIS-based scenario approach was combined with the model BIO-SAFE for cumulative effects assessment (CEA) of physical reconstruction and land-use changes in floodplains. A case study for floodplains in the Middle Waal region visualises effects of various scenarios for ecological rehabilitation and infrastructure facilities on the distribution of riverine ecotopes and on fish, herpetofauna (amphibians and reptiles) and breeding birds. In comparison with the actual situation, all scenarios have negative impact on breeding birds. The saving scenario seems to favour settlement of fish. The preserving scenario appears to be most positive for herpetofauna. Species that will thrive most from future developments are those that prefer hydrodynamic pioneer environments (e.g. side-channels), whereas species that will encounter difficulties are more related to relatively low hydrodynamics (e.g. lakes and isolated river channels) or terrestrial habitats (pastures and hay lands).

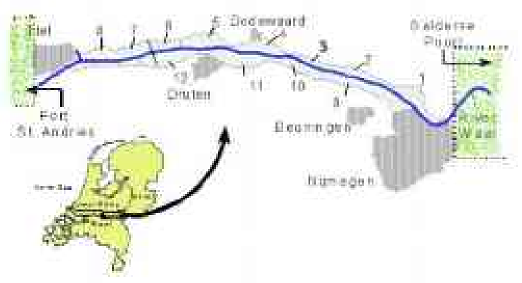

Figure 1. The geographical location of the study area

Introduction
The coming decades northwestern Europe's river basins will be significantly reconstructed for the purpose of flood risk abatement, ecological rehabilitation and infrastructure facilities. The physical reconstruction and land-use changes may offer opportunities to increase biological diversity, but can also seriously endanger present natural values and potentials (Lenders et al., 1998, 2001, De Nooij et al., 2004). Integrated river management will require regional effect assessments of combinations of measures on biodiversity (Leuven et al., 2002). This paper presents a novel method for CEA and evaluates impacts of current spatial plans on riverine biodiversity in the Middle Waal region.

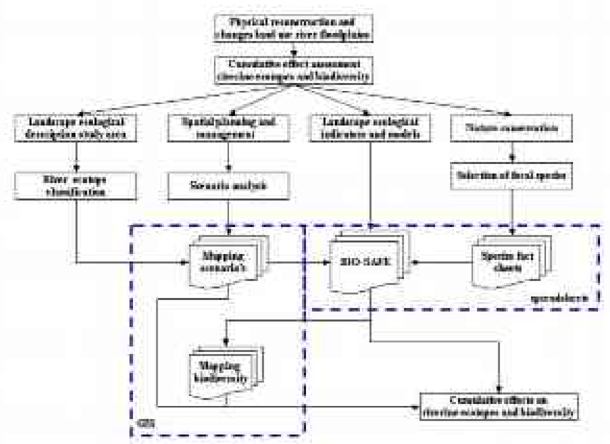

Figure 2. GIS-based procedure for CEA

Material and methods
For eleven floodplains in the Middle Waal region (Fig. 1), a GIS-based scenario approach was combined with the model BIO-SAFE (Fig. 2). BIO-SAFE is a valuation model for riverine biodiversity that focuses on species listed on Red Lists, the EU Habitats and Birds directives, and the conventions of Bern and Bonn (Lenders et al., 2001, De Nooij et al., 2004). Three scenarios project expectations onto the riverine landscape in the year 2015 (Leuven et al., 2002). The preserving scenario comprises current plans for ecological rehabilitation in eight floodplains. The saving and utilising scenarios also includes current plans for new infrastructure facilities (e.g., several harbours, storages for contaminated river sediments and multi-modal transport centres). In the saving scenario, available space is maximally spared as a non-renewable resource and ecological rehabilitation and infrastructure facilities are implemented in accordance with their 'best' spatial alternatives. In the utilising scenario, the available space is largely used for infrastructure facilities and other human

purposes. All spatial data were implemented and analysed in Arcview. GIS allowed comparison of the future scenarios with the reference situation (year 1997) and calculations of surface areas of riverine ecotopes (input for BIO-SAFE).

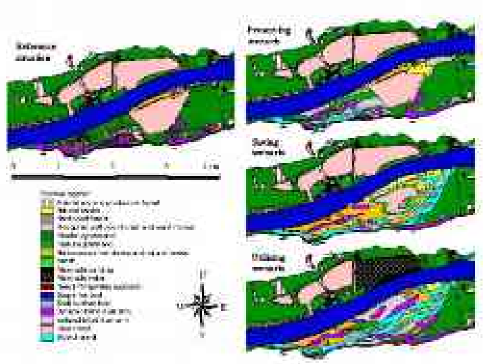

Figure 3. Ecotope maps for development of the floodplains

Figure 3 presents an example of ecotope maps of the reference situation and the three scenarios for the floodplains in the western part of the study area. The acreages of natural ecotopes, agricultural and built-up areas of the Middle Waal region remarkably differ for over the three scenarios (Fig. 4). In comparison with the actual situation, all scenarios have negative impact on breeding birds (Fig. 5).

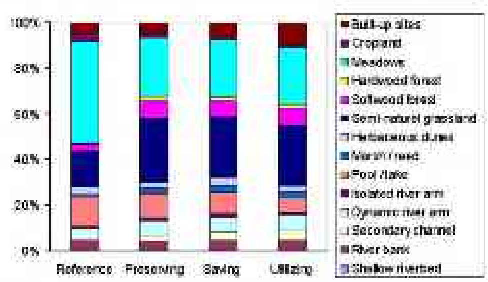

Figure 4. Acreage of river ecotopes.

The utilising scenario appears to have greater impact on breeding birds than the other scenarios. The saving scenario seems to favour settlement of fish, but occupies an intermediate position for herpetofauna and breeding birds. The preserving scenario appears to be most positive for herpetofauna. Species that will thrive most from future developments are those that prefer hydrodynamic pioneer environments (e.g. side-channels), whereas species that will encounter difficulties are more related to relatively low hydrodynamics (e.g. lakes and isolated river channels) or terrestrial habitats (pastures and hay lands). Implementation of plans in accordance with the preserving scenario yields an optimally balanced spectrum of species. However, it should be noticed that the saving and utilizing scenarios heavily rely on compensating measures proposed for infrastructure facilities, whose feasibility is still doubtful at present because of difficulties with land procurement. In addition, several species also require habitat patches outside floodplains in the course of their life cycle. The downside of the abandonment of agriculture in the floodplains is its intensification in the hinterland. This could prove to be quite destructive for ecotopes (in terms of size or quality) for some species like the great reed warbler (reed marshes) or the crested newt (isolated, high quality water bodies). If the occurrence of these species is to be safeguarded, we cannot afford to sacrifice valuable nature areas in the hinterland as a trade-off for improving floodplains (Lenders et al., 1998).

In order to minimise the cumulative effects of infrastructure facilities and flood defence measures and to maximise the benefits of ecological rehabilitation, an integrated plan for physical reconstruction and land-use changes of the study area as a whole should be developed, in which all plans for individual projects in floodplains are mutually attuned. Such a plan should provide conditions that might result in both a higher degree of defragmentation of riverine ecotopes and better opportunities for broad spectra of species. It is only under this precondition that physical reconstruction of floodplains along the middle reach of the river Waal may offer a prosperous future for protected and endangered species.

BIO-SAFE can be easily combined with GIS-based scenario approaches for CEA of riverine area developments and appears to be a useful tool for fine-tuning of spatial plans in early phases of their planning process. Other methods, e.g. detailed single species models taking into account more habitat demands of the species examined, are doubtlessly more subtle and would lead to more accurate predictions of settlement opportunities for biodiversity. However, this would require more detailed input of species-specific parameters as well as of landscape parameters in the target situation. Knowledge of the first type of input still appears to be lacking for many riverine species, while data necessary for the second type of input can in most cases not be derived from floodplain reconstruction plans.

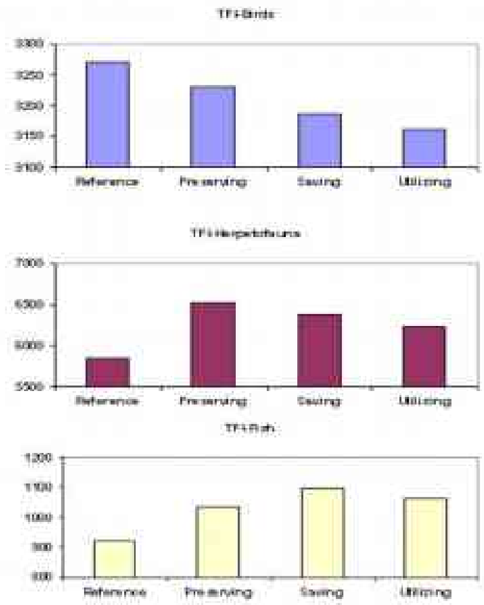

Figure 5. BIOSAFE scores (TFI = Taxonomic group floodplain importance index).

Conclusions

- BIO-SAFE can be easily combined with GIS-based scenario approaches for riverine areas development.
- Physical reconstruction and land-use changes in floodplains along the Middle Waal strongly affect the surface areas and distribution patterns of riverine ecotopes and will have major effects on protected and endangered species in this area.
- In spite of model and scenario assumptions, the results facilitate the debate about and the decision-making process for policy targets of integrated river management.

References

De Nooij, R.J.W., H.J.R. Lenders, R.S.E.W. Leuven, G. de Blust, N. Geilen, B. Goldschmidt, S. Muller, I. Poudevigne & P.H. Nienhuis, 2004. BIO-SAFE: assessing the impacts of physical reconstruction on protected and endangered species. River Research and Applications 20(3), pp. 299-313.

Lenders, H.J.R., R.S.E.W. Leuven, P.H. Nienhuis, R.J.W. de Nooij & S.A.M. van Rooij, 2001. BIO-SAFE: A method for evaluation of biodiversity values on the basis of political and legal criteria. Landscape and Urban Planning 55 (2), pp. 119-135.

Lenders H.J.R., R.S.E.W. Leuven, P.H. Nienhuis, K.D. Oostinga & P.J.M. van den Heuvel, 1998. Ecological rehabilitation of floodplains along the middle reach of the river Waal: a prosperous future for fauna target species? In: P.H. Nienhuis, R.S.E.W. Leuven & A.M.J. Ragas (eds.), New concepts for sustainable management of river basins. Backhuys, Leiden, pp. 115-130.

Leuven, R.S.E.W., Y. Gerig, I. Poudevigne, G.W. Geerling, L. Kooistra & B.G.W. Aarts, 2002. Cumulative impact assessment of ecological rehabilitation and infrastructure facilities in the middle reach of the river Waal. In: R.S.E.W. Leuven, I. Poudevigne & R.M. Teeuw (eds.), Application of geographic information systems and remote sensing in river studies. Backhuys, Leiden. pp. 201-216

Inaccuracies in estimated grain size parameters and their implication on geological models

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Abstract
The accuracy of the measurements of grain size parameters used in a geological model are crucial to the overall reliability of the constructed model. The main goal of the current research is to quantify the reliability of estimated grain size data and to determine the impact that these inaccuracies have on 3D geological models. Only comparisons of sand medians will be presented in this text. The analysis shows that the sand median is underestimated. The effect of the inaccuracies in estimated sand medians on the 3D interpolation of grain size data is evaluated, using two methods, first a visual check and, second the calculation of the Shields parameter. The conclusion is that the inaccuracies of the sand median do not lead to any significant changes in whether or not the sediment is transported or changes in river sedimentation patterns.

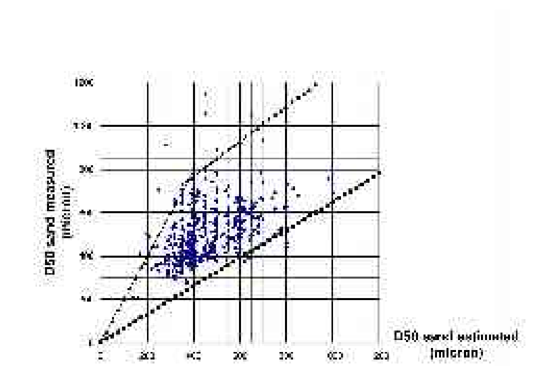

Figure 1. Scatter plot of estimated D50 values and associated measured D50 values. In triangular points the upper boundary of the bandwidth and in squares the lower boundary of the bandwidth. From within this bandwidth the realizations of the sand median are taken.

Introduction
In geological modelling, geostatistics and geological knowledge are used to combine 1D and 2D measurements to a 3D frame of the different (geological) layers in the subsoil. Within these layers different parameters may be estimated. The accuracy of the measurements used in a geological model are crucial to the overall reliability of the constructed model. For morphological models, insight into the variation of the grain size parameters within a layer is dominant.

The main goal of the current research is to quantify the reliability of the used grain size data and to determine the impact that these uncertainties have on geological models.The

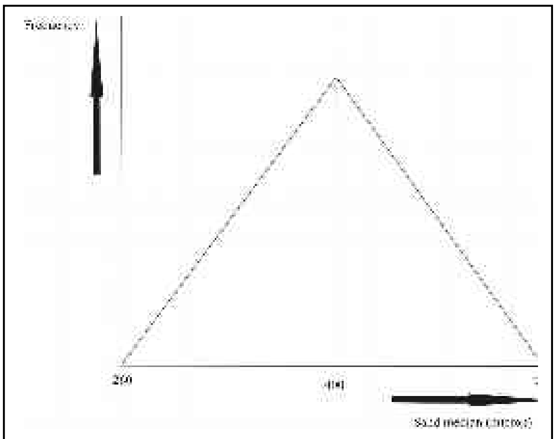

Figure 2. Triangular probability curve of the sand median. In this example an estimated sand median of 400 µm and an associated bandwidth of 260-770 µm; 50 realizations of the sand median are taken from this frequency diagram

data used in this study originated from various projects carried out for the Institute for Inland Water Management and Waste Water Treatment (RIZA) during the years 2001-2003. Samples are taken from vibrocores and are analysed by Fugro B.V. using the sieve method (cf. NEN 2560). All of the samples were also described at TNO-NITG and these descriptions are all stored in the relational database DINO (Databank Informatie Nederlandse Ondergrond); the database of all subsoil data of the Netherlands used at TNO-NITG. In total, approximately 1500 samples have been used for analysis. First, the accuracy of estimated grain size parameters (median grain size of the sand fraction between 63 and 2000 µm (D50), silt content and gravel content) are compared with sieve results. Only comparisons of sand medians will be presented in this text. The effect of these inaccuracies in estimated sand medians on the 3D interpolation of grain size data is evaluated by using a Monte Carlo procedure for a set of samples in the IJsselkop bifurcation in the lower Rhine distributary system in the Netherlands. The inaccuracies in sand medians are transformed into triangular distributions. For every realization, the sand median, gravel and silt content are used to calculate a synthetic grain size distribution (GSD). Together with measured grain size distributions these data are interpolated using 3D kriging (cellsize 25x25x0.2 m).

Results of the analysis of grain size parameters

Of the analysis of the three grain size parameters (sand median, silt and gravel content) only the results of the sand median are presented in this paper. The sand median

Figure 3a. The calculated Shields parameter (θ) for two realizations (a and b), only minor differences can be seen, leading to no differences in whether or not the sediment is transported in this example (θ_{cr}=0.06; threshold of motion).

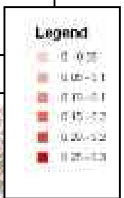

Figure 3b. The calculated Shields parameter (θ) for two realizations (a and b), only minor differences can be seen, leading to no differences in whether or not the sediment is transported in this example (θ_{cr}=0.06; threshold of motion).

is on average underestimated, which can be seen in Figure 1. More details of the inaccuracies and the way they are calculated can be found in Maljers & Gruijters (2004). In the next section the inaccuracies in the sand median are implemented in a geological model, and the implications on this model are discussed.

Implementation and implications of inaccuracies

The implementation of the bandwidth found in analyzing the sand median will be presented below. In Fig. 1 the bandwidth of the sand median is shown (in triangular en square points). This bandwidth means that for samples of which the sand median is estimated as 400 µm, the actual sand median could be between 260 µm (lower boundary of the bandwidth) and 770 µm (upper boundary of the bandwidth).

For modelling, 50 realizations of the sand median are calculated. The values are within the bandwidth and follow a (random) triangular probability curve. This results in 50 different realizations of the sand median. For example the range of measured sand medians belonging to an estimated sand median of 400 µm, is between 260 µm and 770 µm. The main point will be around 400 µm (Fig. 2).

The other two grain size parameters of importance in constructing synthetic GSDs are the silt content and the gravel content. Silt content in this research has been set to 1% for all samples and during all realizations. The gravel content has been estimated for all samples and this value is used in modelling. This means that, during each realization the only parameter that differs is the sand median. Details about constructing synthetic GSDs are fully discussed in the NCR-publication 24 (Gruijters et al., 2004) and will therefore not be presented in this paper.

The implications on a geological model of the inaccuracies in the sand median can be shown in two ways. First of all a visual check has been made; second, the Shields parameter, which is a dimensionless measure for the transport of sediment, has been calculated for two realizations in combination with two river discharges (normal and high).

For the visual check, the median of the whole sample of the top of the Kreftenheye deposits has been used instead of the top of the mobile pavement, because the active layer was sampled in great detail and has therefore only measured GSDs. Therefore the bandwidth of the sand median and the associated synthetic GSDs will not affect the top of the mobile pavement. Only in details do the two realizations of the top of the Kreftenheye deposits differ in D50.

The implementation of the bandwidth of the estimated sand median does not seem to have any influence on river sedimentation patterns.

The calculated Shields parameter, has also been calculated for the top of the Kreftenheye deposits. When looked at the actual values for the Shields parameter for two realizations during normal discharges, minor differences can be seen (Fig. 3). Because the Kreftenheye sediment is not very coarse, the threshold of motion (which is set to 0.06) is already exceeded for most cells; therefore the minor differences in the Shields parameter do not lead to any difference in whether or not the sediment is transported.

Conclusions

Based on the aforementioned methods it can be concluded that the applied bandwidth to the estimated sand median does not influence the sedimentation patterns or whether or not the sediment is transported. This means that the method described in Gruijters et al. (2004) to use synthetic grain size distributions based on estimated parameters is indeed a step forward in describing the natural variation in the subsoil of a riverbed.

Acknowledgements

The authors would like to thank RIZA, Roy Frings and Maarten Kleinhans.

References

Gruijters, S.H.L.L., D. Maljers, J.G. Veldkamp, J. Gunnink, M.P.E. de Kleine, P. Jesse, L.J. Bolwidt, 2004. IJSSELKOP: modelling of 3D grain size distributions, one step closer to reality. In: N. Douben & A.G. van Os (eds.), NCR-days 2003; dealing with floods within constraints. NCR-Publication 24-2004, Netherlands Centre for River Studies, Delft, pp. 80-82.

Maljers, D. & S.H.L.L. Gruijters, 2004. Geological modelling: how realiable are input parameters? In: N. Douben & A.G. van Os (eds.), NCR-days 2003; dealing with floods within constraints. NCR-Publication 24-2004, Netherlands Centre for River Studies, Delft, pp. 86-87.

Supply-limited transport of bed-load sediment at the IJsselkop

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Abstract
Bed-load transport calculations based on multibeam echo soundings suggest that the sediment transport at the IJsselkop is suppressed by a limited supply of transportable sediment. This probably results from bend sorting processes at the river bifurcations Pannerdensche kop and IJsselkop.

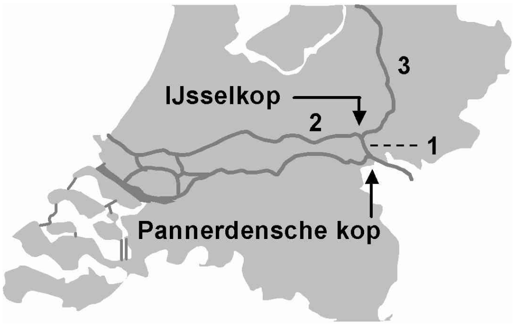

Figure 1. Rhine branches at the IJsselkop bifurcation, the Netherlands: 1 = Pannerdensch Kanaal, 2 = Neder-Rijn, and 3 = IJssel

Introduction
The river bifurcations Pannerdensche Kop and IJsselkop determine the sediment and water distribution over the central part of the Netherlands (Fig. 1). A good understanding of this distribution process is crucial for operational river management. It is known that only a small part of the bed-load sediment that arrives at the Pannerdensche Kop bifurcation is directed towards the Pannerdensch Kanaal (Kleinhans, 2002). Therefore, the IJsselkop bifurcation, which is situated at the end of the Pannerdensch Kanaal, may be subject to a limited supply of transportable sediment. The purpose of this study was to determine whether the bed-load sediment transport at the IJsselkop is supply-limited.

Methods
We used multibeam echo soundings in combination with a dune tracking technique to determine the bed-load transport rate at the IJsselkop. We thus assumed the sediment transport to be zero when dunes are absent, which is realistic according to direct transport measurements with a Delft Nile Sampler (Frings, unpublished data). The multibeam echo soundings that we used were conducted during discharge waves in November 2002 and January 2004. The resolution of these echo soundings enabled us to determine the temporal, longitudinal and lateral variation in sediment transport.

Results
The lateral variation in sediment transport was large, especially in the Pannerdensch Kanaal. The absence of dunes near the edges of the river indicates that the sediment transport was limited to a clearly demarcated zone in the middle of the river (Fig. 2).

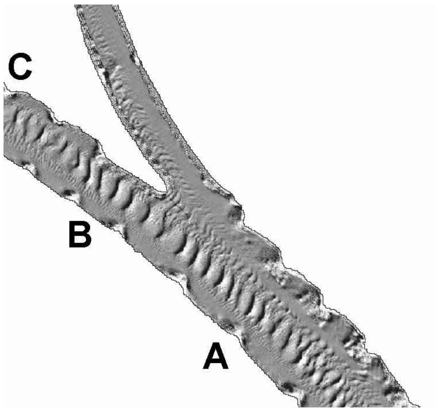

Figure 2. Bed image of the IJsselkop bifurcation, November 2002. A,B,C refer to the sections described in Figure

The temporal variability in sediment transport during the 2004 discharge wave is shown in Fig. 3, for three river sections. In the first section, the Pannerdensch Kanaal, the maximum sediment transport rate occurred well before the peak discharge. In the other sections, both in the Neder-Rijn, the maximum sediment transport rate occurred much later; in the downstream-most section even two weeks after the peak discharge. The long-term temporal variability is also pronounced: in 2002 the sediment transport was almost twice as high as in 2004 at the peak of the discharge wave, which was about 6500 m^3/s at Lobith in both years.

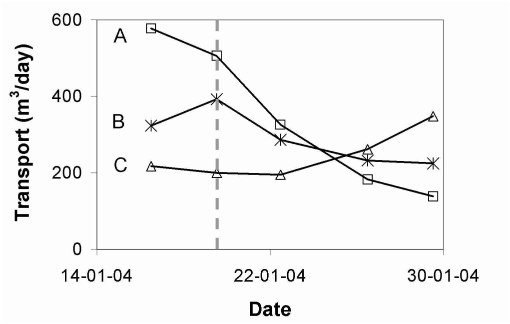

Figure 3. Temporal variation in sediment transport during the January 2004 discharge wave in three river sections (A, B, C). The location of the three river sections is shown in Figure 2. The moment of the peak discharge is indicated with a dashed line

Figure 4 shows the water and sediment distribution at the IJsselkop. The Neder-Rijn received about 90 % of the sediment load in the Pannerdensch Kanaal and 57 % of the water discharge, while the third river branch, the IJssel, received an almost equal amount of water (43 %), but only 10 % of the sediment load.

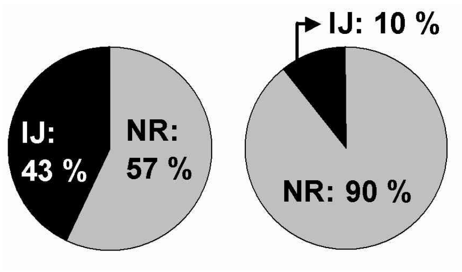

Figure 4. Water distribution (left) and sediment distribution (right) at the IJsselkop during the 2002 and 2004 discharge waves. IJ: IJssel; NR: Neder-Rijn

Discussion

All results support the idea of supply-limited transport. Namely, in the case of redundant transportable sediment, dunes would have occurred over the entire river width, while the sediment transport rates in 2002 and 2004 would have been the same. Furthermore, the moment of maximum sediment transport would have been equal for the Pannerdensch Kanaal and the Neder-Rijn. The downstream shift in moment of maximum sediment transport points at a sediment wave that moved from the Pannerdensch Kanaal into the Neder-Rijn during the 2004 discharge wave. A sand wave has also been observed at the Pannerdensche Kop (Kleinhans, 2002), suggesting that sediment waves are a structural phenomenon at bifurcation points.

The supply-limitation is probably larger in the IJssel than in the other branches of the IJsselkop, because the IJssel receives hardly any sediment. We expect this to be the result of the interaction between sediment transport and bed grain size (Fig. 5), in the following way.

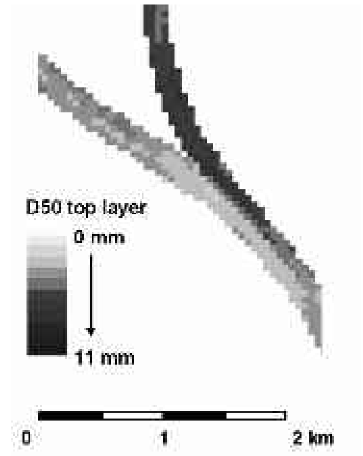

Figure 5. Grain size of the top of the riverbed at the IJsselkop (after Gruijters et al., 2003).

Bend sorting in the meander bend upstream of the IJsselkop causes the bed sediment at the entrance of the IJssel to be much coarser than the bed sediment at the entrance of the Neder-Rijn. This coarse material probably is only mobile at high discharges, leading to a limited supply of transportable sediment into the IJssel at low discharges and at intermediate discharges like those in 2002 and 2004. The same process can be held responsible for the limited supply of sediment into the Pannerdensch Kanaal at the Pannerdensche Kop.

The supply limitation has severe implications for the prediction of sediment transport rates, as theoretical transport predictors all assume a redundant amount of transportable sediment. Empirical predictions are problematic too, because the supply-limitation is not constant in time. In 2002 the sediment transport was much higher than in 2004, while the discharge was the same. For reliable predictions of sediment transport at the IJsselkop, therefore, the sediment transport history needs to be taken into account.

Acknowledgements

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References

Gruijters, S.H.L.L., J. Gunnink, J.J.M. Hettelaar, M.P.E. de Kleine, D. Maljers & J.G. Veldkamp, 2003. Kartering ondergrond IJsselkop; eindrapport. TNO-rapport NITG 03-120-B. Nederlands Instituut voor Toegepaste Geowetenschappen TNO, Utrecht.

Kleinhans, M.G., 2002. Sorting out sand and gravel: sediment transport and deposition in sand-gravel bed rivers. Netherlands Geographical Studies 293, KNAG/Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht, Utrecht, 317 p.

Morphological behaviour around bifurcation points; preliminary results of recent measurements

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Abstract
To determine the morphological behaviour of bifurcation points two measurement campaigns were set up and performed in January 2004 and September 2004. A variety of measurements was performed successfully, resulting in a unique database on bifurcation points. These first results are promising.

Introduction
The goal of this study is to determine the morphological behaviour of bifurcation points. Bifurcation points play a key role in the water and sediment movement of a river system. In the Netherlands there are three main bifurcation points: (1) Pannerdensche Kop (Boven-Rijn divides into Pannerdensch Kanaal and Waal); (2) Merwedekop (Boven-Merwede divides into Beneden-Merwede and Nieuwe Merwede); (3) IJsselkop (Pannerdensch kanaal divides into IJssel and Neder-Rijn).

Measurement campaign
In January 2004 measurements on subsoil, sediment transport, active layer, water level, discharge, flow velocity and direction, were performed with 10 ships during high discharges at the IJsselkop and the Merwedekop. The campaigns lasted two weeks. In Fig. 1 the water levels can be seen together with the moments of measurements. Comparable measurements at the Pannerdensche Kop had been performed earlier, in 1998. In September 2004 measurements on sediment transport and discharges were performed at the IJsselkop during low discharges to determine the effect of the weirs in the Neder-Rijn. With the MEDUSA technique (Koomans, 2004) the variation of the natural radioactivity of the sediment was determined, by dragging a sensor that measures the natural radioactivity of the sediments, over the river bed. There is a relationship between the radioactivity and the grain size. Three surveys at different discharges were carried out to determine the change in grain size patterns of the top layer. In this way, it was possible to detect sorting processes and bed roughness patterns.

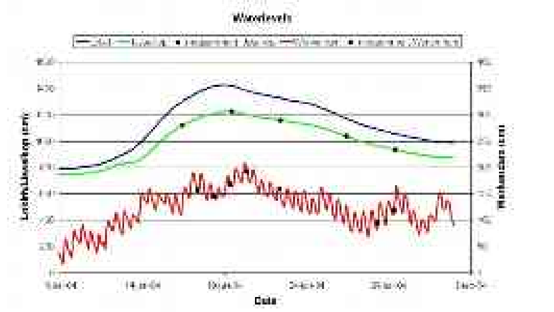

Figure 1. The water levels during the measurement campaigns at the IJsselkop and at the Merwedekop (Werkendam).

Preliminary results
The data of the IJsselkop have been analysed first. In Fig. 2, the results of a MEDUSA scan of the grain size patterns after the peak discharge can be seen. In the Pannerdensch Kanaal the dune height reacts quickly on increasing discharge, with a maximum of ca 50 cm, reached at the peak discharge. Migration speed decreases with increasing dune height and vice versa. The highest and longest dunes were formed in the Pannerdensch Kanaal and the Neder-Rijn. More results are described in the paper of Frings & Kleinhans in this volume.

Conclusions
A variety of measurements was performed successfully and the measurement results constitute a unique database on the morphological behaviour of bifurcation points. The results from the IJsselkop show a clear differences between the three branches, with respect to subsoil, sediment transport, grain size and dune characteristics. The Merwedekop measurement results are presently under study. Both studies will result in an integral report on the different data.

From the studies around the Pannerdensche Kop a clear view of the distribution of water and sediment on the bifurcation point Pannerdensche Kop has been obtained. The data helped to gain more insight into the morphological behaviour of this bifurcation point. Much of these data were used in two dissertations on the behaviour of sand dunes and sorting processes of sediments.

Co-operation

This research has been performed under the authority of Rijkswaterstaat (DZH and DON), in co-operation with Utrecht University, TNO-NITG, MEDUSA Explorations BV and the Morphological Triangle of NCR.

Reference

Koomans, R., 2004. Hoogwater op de IJsselkop, eind-rapport, 2003-p-029R3. MEDUSA Explorations BV, Groningen

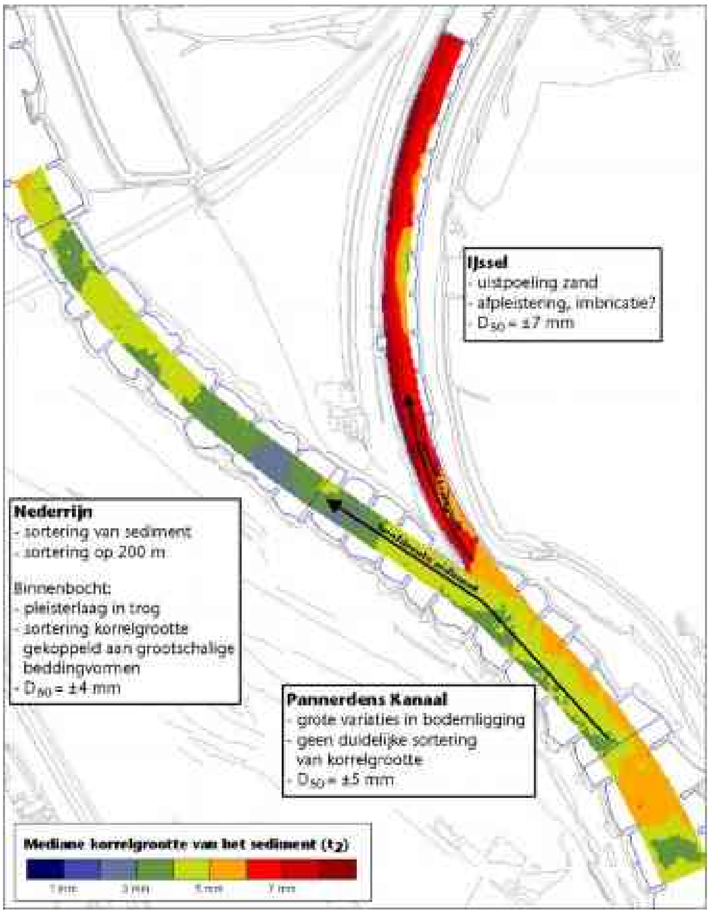

Figure 2. Spatial distribution of bed material grain sizes near the IJsselkop after peak discharge. The main route of the sediment runs from the Pannerdensch Kanaal to the Neder-Rijn. During high discharges erosion takes place in the IJssel channel. The finer material is washed away leaving coarser material in the top layer.

Channel roughness in 1D steady uniform flow: Manning or Chézy?

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Abstract
In river flow applications, consensus on the most appropriate roughness descriptor has yet to be found. A disturbing observation is that the coefficients and formulae of Chézy, Darcy-Weisbach, Manning, Strickler and White-Colebrook are used rather arbitrarily, and that a widely accepted scientific justification is lacking. The presented paper compares the most commonly used roughness parameters, and reflects on some arguments that are often used in favour of, or against, any of these. Some recent advances on the theoretical basis of different methods are put forward, and implications for commonly used hydraulic modelling packages are discussed.

Commonly used roughness relations
For open channels, three different formulae are commonly used to describe the relation between the mean flow field and channel resistance in the steady uniform case. For completion, the Darcy-Weisbach equation is included, but will not be further reflected upon, because of its functional equivalence to the Chézy equation. The dates mentioned below for the Chézy, Darcy-Weisbach and Manning formulae are from a historical overview by Rouse & Ince (1957); the White-Colebrook equation was published by Colebrook (1939).

1. Chézy (1769): $U = C\sqrt{Ri}$, where $C = 18\log(12R/k_N)$ "White-Colebrook (1939)"
2. Darcy-Weisbach (1840's-50's): $U = \sqrt{8g/f}\sqrt{Ri}$
3. Manning (1889): $U = (1/n)R^{1/6}\sqrt{Ri}$, where $n = k_S^{1/6}/25$ "Strickler (1923)"

Where k_N is the Nikuradse (1933) roughness height in the White-Colebrook equation (adapted for hydraulically rough flow), and k_S the roughness height by Strickler. Originally, the equations above are all empirical in character, giving each of them validity in at least some specific situations. Since they are supposed to describe the mean flow velocity (U) as a function of roughness (C, n or f) and geometry (hydraulic radius R, slope i), the question arises which formula gives the simplest, yet most widely applicable, representation in a (natural) open channel?

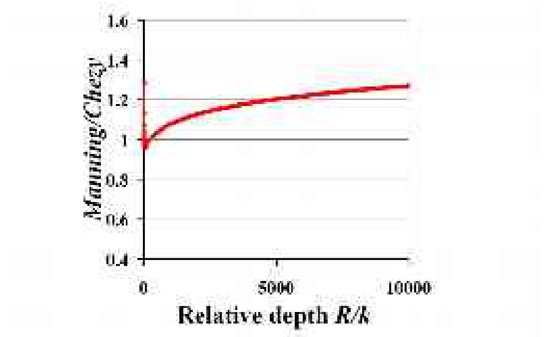

Figure 1. Comparing the Manning equation (roughness height as in Strickler) with the Chézy equation (roughness height as in White-Colebrook): although the two formulae are clearly not equal, they show similar behaviour with respect to increasing relative roughness (hydraulic radius R/ roughness height k) because of the decreasing gradient of the fraction-function.

Presently, there is no consensus on this matter and conflicting arguments remain to be heard. It is often argued that the Chézy equation (or Darcy-Weisbach for that matter) has a sound theoretical basis (see for derivation Jansen, 1979), which would justify its wider range of use. However, Gioia & Bombardelli (2002) have shown that similarity considerations of flow in the hydraulically rough regime lead to the Manning equation, where n is a measure of the absolute roughness height (as in Strickler's relation). In this respect it is not yet clear which theoretical foundation is most reliable, leaving the issue unresolved. In Fig. 1 the two formulations are compared with respect to changing relative depth. The figure shows that fundamental differences between the two approaches exist. How this affects performance of hydraulic models is discussed in the following sections.

Calibration in a simple channel

According to their respective theoretical foundations, both the Chézy and the Manning equation are only expected to be valid in situations where sidewall effects are negligible. As a result, situations with wide channels (depth<<width of channel) have to be considered. Although Fig. 1 shows that both descriptions may differ significantly, still both can be made to fit data by allowing the respective roughness heights in each description to vary independently (assume different roughness height definitions). Consider for example a simple channel of width 100 m where a discharge of 300 m^3/s results in a water depth of 2.5 m (slope i = 0.01 %). In this case the Chézy equation (with White-Colebrook) yields a roughness height of k_N = 1.8 mm, while the Manning equation (with Strickler) gives k_S = 3.1 mm. If these calibrated formulae are subjected to an increased discharge of 20% (360 m^3/s) a water level difference of 1.3 cm results (~3% of total water level rise, see Fig. 2). As could be expected, Fig. 2 shows that the two formulations follow a similar behaviour when made to fit each other at a specific (calibration) point.

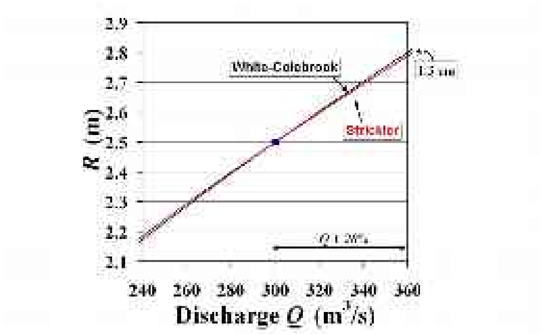

Figure 2. Difference in predicted water levels (~hydraulic radius R) at 20% discharge increase when both the Manning and Chézy equation are calibrated on Q = 300 m^3/s and R = 2.5 m (see text for chosen geometry).

Calibration in a composite channel

In a composite channel the overall roughness may be computed by using a divided channel method (e.g. Chow, 1957; Jansen, 1979; Yen, 2002). This method assumes that flow in each of the subsections is independent from other section and that the total discharge equals the sum of section-discharges. The approach may be expected to be valid if the different sections are wide, such that possible lateral transfer mechanisms at the interfaces can be neglected. In Chow (1957) an indicative value of 10 for the relative width (as compared to water depth) is given for a channel to be considered wide. Consequently, for two-stage channel this argument is taken to count for each of the subsections. Fig. 3 shows a two-stage channel with overall flow conditions that resemble the previously mentioned case in a simple channel: the overall hydraulic radius is 2.5 m, the total width is 100 m and the discharge is 300 m^3/s.

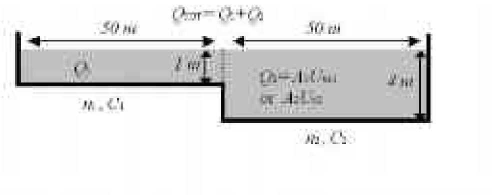

Figure 3. Cross-section of a two-stage channel (A = cross-section subarea) showing relevant parameters for divided channel method. If the roughness parameters (n, C) in subsections are calibrated to fit a discharge of 300 m^3/s (at a slope of 0.01%), then an increased discharge predicts different water levels between the 2 calibration sets (one based on addition of Chézy formulae U_C in subsections, the other on Manning U_m).

In order to calibrate the composite roughness equations on these specific conditions, roughness parameters for each of the subsections have to be determined. In the case considered here, the following roughness values are made to correspond to flow conditions: Manning's n = 0.05 s/$m^{1/3}$ in the floodplain and n= 0.017 s/$m^{1/3}$ in the main section (corresponding to C=20.0 $m^{1/2}$/s and C=72.5 $m^{1/2}$/s, respectively). Note that calibration is not performed on roughness heights but on resistance coefficients C and n, as is often the case in practice. In real situations the roughness in the main sections may be determined independently at low water levels (flow below bankfull height). If, again, discharge is increased to 360 m^3/s (+20%), different water levels result from using two different methods. In this case the water level difference turns out to be about 5 cm (~11% of total water level rise), significantly higher than in the simple channel case.

Conclusions

For both the Manning and the Chézy equation, follow-up work provided a theoretical foundation. However, between the two, there remains a fundamental difference with regard to the dependence on the hydraulic radius (C depends on R, while n does not). In a simple channel the methods show equivalent behaviour when used for extrapolating beyond the level of the highest calibration point. In the specific case presented, a water level difference of 1.3 cm resulted after a 20% discharge increase. While theory shows that the Chézy parameter is a measure of relative roughness height, its value is often treated as a constant in methods to determine a composite roughness in more complex river geometries. This method seems more justified when using the Manning roughness parameter since theory predicts that this parameter is indeed a true measure of (absolute) wall roughness. Calibration of both Chézy and Manning on specific flow conditions consequently gives a much larger discrepancy in predicted water level than in the simple channel case, where calibration is performed on roughness height and thus theory is followed more closely. In the composite channel case presented, the discrepancy amounted to 5 cm (higher water level in Chézy approach) at a 20% discharge increase (equivalent composite characteristics as in the simple channel case).

In conclusion, for composite roughness methods it is advised to apply the Manning approach for roughness calibration, in order to give a theoretically correct weight to the roughness of each subsection.

References

Chow, V.T., 1959. Open-channel hydraulics. McGraw-Hill, New York.

Colebrook, C.F., 1939. Turbulent flow in pipes, with particular reference to the transition region between the smooth and rough pipe laws, Journal of the Institute of Civil Engineers (London), 11, pp. 133-156.

Gioia, G. & F.A. Bombardelli, 2002. Scaling and similarity in rough channel flows. Physical Review Letters 88(1), pp. 14501/1-4.

Jansen, P.Ph., 1979. Principles of river engineering. (Facsimile edition 1994) Delftse Uitgevers Maatschappij, Delft.

Nikuradse J., 1933. Strömungsgesetze in Rauhen Rohren, Forschungsheft 362, vol. B., VDI Verlag, Berlin.

Rouse, H. & S. Ince, 1957. History of hydraulics. Dover Publications, New York.

Strickler, A., 1923. Beitrage zur Frage der Geschwindigkeitsformel und der Rauhigkeitszahlen für Ströme, Kanäle und geschlossene Leitungen. Mitteilungen des eidgenossischen Amtes für Wasserwirtschaft, 16, Bern.

Yen, B.C., 2002. Open channel flow resistance. Journal of Hydraulic Engineering 128(1), pp. 20-39

3D float tracking: in-situ floodplain roughness estimation

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Abstract
3D float tracking is a new method to quantify hydrodynamic roughness of submerged floodplain vegetation. In this method a floating tripod is released on the inundated floodplain and tracked from shore by a tachymeter leading to a highly detailed representation of the water surface elevation along the flow path. Simultaneously, an Acoustic Doppler Current Profiler collects flow velocity profiles and water depth. Preliminary roughness values, based on backwater-curve modelling and the 1D equation for non-uniform flow, range less than one order of magnitude.

Introduction
Hydrodynamic roughness of submerged vegetation is an important parameter for river flow models. Roughness values are mostly based on flume experiments, carried out with low water depths and high water surface slopes (Carollo et al., 2002; Wilson & Horrit, 2002). These experiments do not represent the hydrodynamic conditions of lower Rhine floodplains well. For roughness estimation from hydrodynamic parameters detailed information is needed on the water surface slope, water depth and depth averaged flow velocity (Van Rijn, 1994). The local water surface slope has always been a difficult parameter to measure due to the small differences in water level. Therefore the aim of this research is to collect accurate and detailed field measurements of water surface slope, water depth and depth-averaged flow velocity and to determine the hydrodynamic roughness of submerged floodplain vegetation. This can be done with a new method: 3D float tracking.

Materials and methods
Measurements were taken with a tripod floating on the inundated floodplain (Fig. 1). An Acoustic Doppler Current Profiler (ADCP) mounted underneath the float measured (1) the float velocity using the bottom track option plus (2) deviations from the float velocity in the water column and (3) the water depth. Results were averaged over 5 seconds to decrease noise. Positioning is done with a shore-based tachymeter that automatically tracks the reflector on top of the float. Positioning was done with a 2 Hz frequency. Changes in position gave the float velocity and the water surface slope. This resulted in detailed information for roughness calculation.

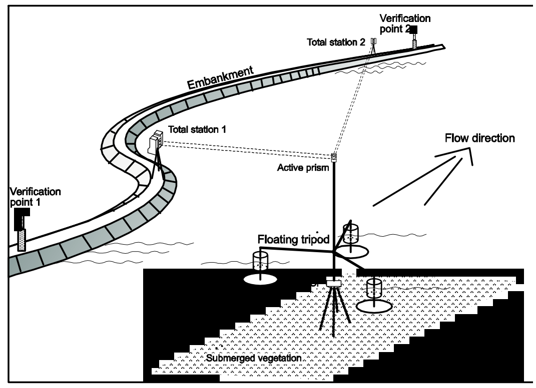

Figure 1. 3D impression of the 3D float tracking method.

Results
In January 2004 the method was tested for the first time on two inundated floodplains: (1) the 'Groene rivier' in Arnhem (Fig. 2) and (2) a floodplain on the river Waal upstream of Zaltbommel. Figure 2 shows the float data of one run in the 'Groene rivier' floodplain in Arnhem. Table 1 shows the key hydrodynamic characteristics of the two floodplains. The water surface slope in Arnhem was measured more accurately than on the river Waal due to the absence of waves. ADCP measurements showed a fair amount of noise. However, averaged flow velocity profiles were consistent from one run to the other.

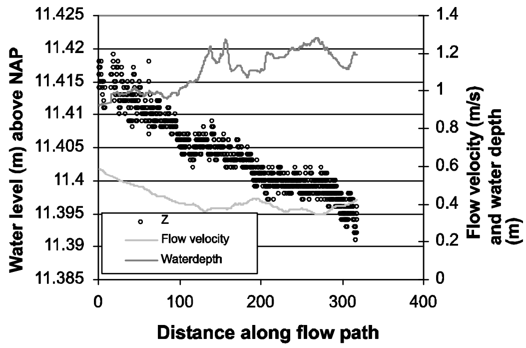

Figure 2. Float data of one run in the 'Groene Rivier' floodplain in Arnhem. Open dots (Z) represent individual water-level measurements.

Preliminary roughness values (Nikuradse's k) in Arnhem were 5 cm ± 3 cm, based on the predictor-corrector method and 8 cm ± 10 cm, based on the locally solved 1D equation for non-uniform flow. Roughness values for the Waal floodplain were not calculated due to the large amount of scatter in the local water surface slopes.

Discussion and conclusions

3D float tracking can supply spatially distributed water surface elevations with unprecedented detail. Together with the flow-velocity and water-depth measurements of the ADCP it generates all necessary data for roughness calculations. However, the accuracy of the method is limited by wave activity.

Derived roughness values are within one order of magnitude. Further improvements are expected from more suitable window sizes for spatial filtering of water surface slope and local flow accelerations. The method can also be extended to roughness measurements of hedges, groynes or minor embankments.

References

Carollo, F.G., V. Ferro & D. Termini, 2002. Flow velocity measurements in vegetated channels. Journal of Hydraulic Engineering 128(7), pp. 664-673.

Van Rijn, L.C., 1994. Principles of fluid flow and surface waves in rivers, estuaries, seas and oceans. Aqua publications, Amsterdam.

Wilson, C.A.M.E. & M.S. Horrit, 2002. Measuring flow resistance of submerged grass. Hydrological Processes 16, pp. 2589-2598.

Table 1. Key hydrodynamic characteristics of the two floodplains.

Floodplain	WSS (cm/km)	Water depth (m)	Flow velocity (m/s)
Arnhem	5.9	1.2	0.41
Waal	8.8	2.5	0.74

WSS = water surface slope

Variations in roughness predictions (flume experiments)

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Abstract
Data of flume experiments with bed forms are used to analyze and compare different roughness predictors. In this study, the hydraulic roughness consists of grain roughness and form roughness. We predict the grain roughness by means of the size of the sediment. The form roughness is predicted by three approaches: Van Rijn (1984), Vanoni & Hwang (1967) and Engelund (1966). The total roughness values (friction factors) are compared with the roughness values according to the Darcy-Weisbach equation. Results show that the different methods predict different friction factors. In future research uncertainties in the hydraulic roughness will be taken into account to determine their influence on the computed water levels.

Introduction
In the Netherlands, the heights and strengths of dikes and other flood defense systems are based on computed water levels which occur during a certain extreme discharge, i.e. the design discharge. The uncertainty in the hydraulic roughness of the river bed is one of the main sources of uncertainty in these computed water levels (Van der Klis, 2003). The purpose of the present research is to compare different state-of-the-art roughness predictors and examine the influence of the roughness predictor on water levels. We use the same approach as Julien et al. (2002). The overall aim of this study is to gain knowledge on the size and type of uncertainties in the hydraulic roughness and their influence on computed water levels.

Material and methods
Flume experiments were conducted by Blom et al. (2003) in the sand flume facility at WL|Delft Hydraulics in the Netherlands (1997-2000). The experiments were performed under steady uniform flow conditions and sediment from the Waal River (near the Pannerdensche Kop) was used. The experiments were aimed at conditions with bed forms. Their heights (Δ) and lengths (Λ) were measured, as well as the hydraulic radius (R), flow depth (h), flow velocity (u) and the energy slope (i). We derive the friction factors by means of two different methods. The first method gives the reference values. It uses flow data and the Darcy-Weisbach equation:

$$f = \frac{8gRi}{u^2} \tag{1}$$

The second method for calculating the roughness is using a roughness predictor. In these experiments the only sources of roughness are grain roughness f ' (caused by the protrusion of grains from the bed into the flow) and form roughness f '' (created by the pressure differences over bed forms). The sum of grain and form roughness gives the total roughness. To calculate the grain roughness we distinguish between a roughness height (k'_s) of d_{90} and $3d_{90}$. The value of the roughness height can be converted to a value for f ' with the following relation (Van Rijn, 1993):

$$f' = 0.24\left(\log\frac{12R}{k'_s}\right)^{-2} \tag{2}$$

For calculating the form roughness we study three models. For the Van Rijn (1984) approach (3), a value for f''_R is obtained by applying equation (2) (using k''_s instead of k'_s).

$$k''_s = 1.1\Delta\left(1 - e^{-25\frac{\Delta}{\Lambda}}\right) \tag{3}$$

The other two models are the Vanoni & Hwang (1967) approach:

$$f''_{VH} = \left(3.3\log\frac{\Lambda R}{\Delta} - 2.3\right)^{-2} \tag{4}$$

and the Engelund (1966) approach:

$$f''_E = 10\frac{\Delta^2}{R\Lambda}e^{-2.5\frac{\Delta}{h}} \tag{5}$$

Results and preliminary conclusions
Figure 1 shows some results of the calculations. The experiments T5, T7, T9 and T10 were conducted under different flow conditions, i.e. different discharges, velocities and slopes. All roughness predictors yield a larger friction factor than the Darcy-Weisbach reference value. From other calculations it

appears that a difference of 0.05 in the friction factor (f) can lead to a 20 cm change in hydraulic radius (R), and thus a significant change in water levels. The results give a first impression of the uncertain hydraulic roughness and show that variations in friction factors influence calculated water levels.

Further research

Plans for future research are first to choose the most appropriate roughness predictor (based on the flume experiments). Then, we want to include uncertainties and perform a Monte Carlo analysis to examine the influence of the uncertain hydraulic roughness on water levels. Furthermore, we will examine what the results of the flume experiments mean for field situations.

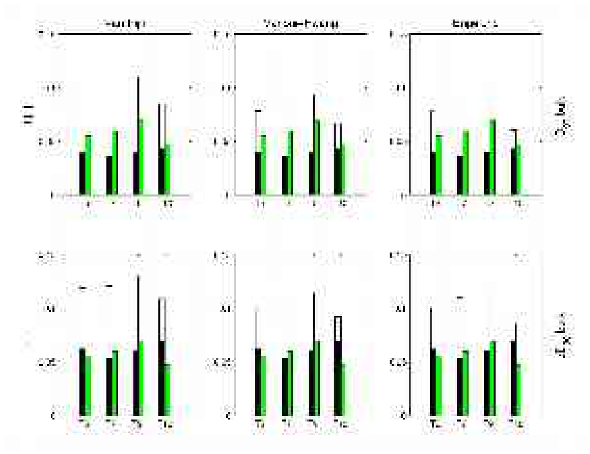

Figure 1. Friction factors,
black = grain roughness,
white = form roughness,
green = Darcy-Weisbach roughness

Acknowledgements

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References

Blom, A., J.S. Ribberink & H.J. de Vriend, 2003. Vertical sorting in bed forms: flume experiments with a natural and a trimodal sediment mixture. Water Resources Research 39 (2), 1025, doi: 10.1029/2001WR001088.

Engelund, F., 1966. Hydraulic resistance of alluvial streams. Journal of the Hydraulics Division 98 (HY2), pp. 315-326.

Julien, P.Y., G.J. Klaassen, W.B.M. ten Brinke & A.W.E. Wilbers, 2002. Case study: bed resistance of Rhine River during 1998 flood. Journal of Hydraulic Engineering 128 (12), pp. 1042-1050.

Van der Klis, H., 2003. Uncertainty analysis applied to numerical models of river bed morphology. Ph.D. thesis, Delft University of Technology, Delft.

Van Rijn, L.C., 1984. Sediment transport, part III: bed forms and alluvial roughness. Journal of Hydraulic Engineering 110 (12), pp. 1733-1754.

Van Rijn, L.C., 1993. Principles of sediment transport in rivers, estuaries and coastal seas. AQUA Publications, Amsterdam.

Vanoni, V.A. & L.S. Hwang, 1967. Relation between bed forms and friction in streams. Journal of the Hydraulics Division 93 (HY3), pp. 121-144

Effect of main channel roughness on water levels

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Introduction

As a result of changing discharge during floods, dunes may develop in the main channel of a river (Fig. 1) leading to a changing bed roughness. This roughness is dynamic since dune dimensions and roughness lag the discharge. In current practice, hydraulic models are tuned using the roughness of the main channel as a calibration factor; the real dynamics of roughness are not taken into account. The aim of our research is to formulate an appropriate model concept for dynamic roughness during floods. This paper presents an analysis of the effect of main channel roughness on water levels. Not the variation of dunes is considered, but only the effect of variations of their roughness. It is also analyzed how the influence of main channel roughness depends on the geometry of the channel.

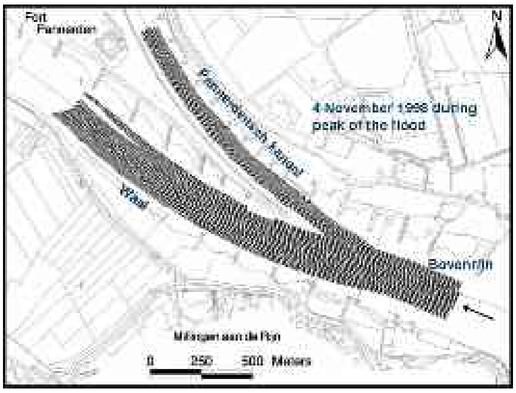

Figure 1. Dunes at Pannerdensche Kop (Wilbers, 2004).

Method

The sensitivity analysis is performed in analogy to Huthoff & Augustijn (2004), using both a numerical and an analytical approach. Floodplain roughness is set constant at k = 0.25 m (Van Velzen, 2003). Calculations are performed for a schematized channel of 100 km as shown in Figure 2a.

In the analytical approach, for simplicity no backwater effects are included. The composite channel roughness (C_{comp}) can be expressed as:

$$C_{comp} = \alpha \cdot (D_T)^{3/2} \cdot C_m + (1-\alpha) \cdot h^{3/2} \cdot C_f$$

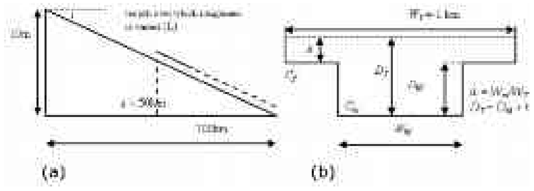

Figure 2. Model schematization; (a) longitudinal, (b) cross-section.

Varied parameters are (Fig. 2): discharge: Q = 500 – 10500 m^3/s; depth of the main channel: D_T = 3 – 5 m; ratio of main channel width to the total width of the cross-section: $\alpha = W_m/W_T$ = 0.2 – 1; main channel bed roughness: k = 0.05 – 0.65 m, the latter is the maximum value observed during a large flood in the Rhine in 1995 (Julien et al., 2002); length of the area over which the roughness is changed (in the numerical approach): L = 0 – 50 km.

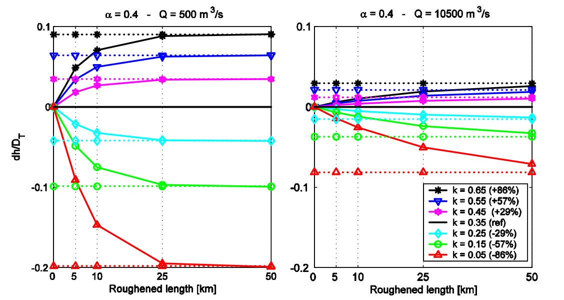

Figure 3. Comparison of analytical (dashed) and numerical (solid) computations for two different discharges. Water-level differences are scaled with the total depth in the reference case (i.e. k_m = 0.35 m).

Results

Results are presented by comparing with a reference case in which the roughness height k of the main channel is 0.35 m. As expected, an increased main channel roughness leads to increased water levels (Fig. 3). At lower water levels (lower discharges), the influence of bed roughness is larger. For a floodplain width of 400 m (α = 0.4 in this case) and a discharge of 10500 m^3/s ($D_T \approx$ 9.9 m), the influence of main channel roughness on absolute water-level difference varies between -80 and +30 cm. The influence of a changing main channel roughness on the relative water level increases, when the ratio of main channel width to total width (α) increases (Fig. 4), since more water flows through the main channel. For a floodplain width of 400 meter, the influence of main channel roughness on the water level varies between +40 and -100 cm.

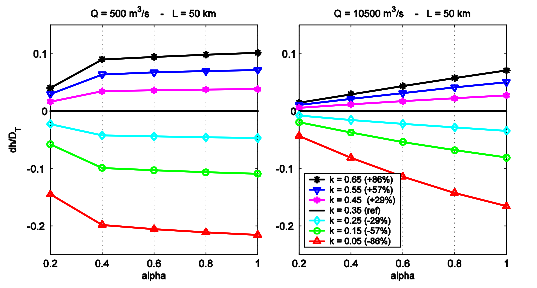

Figure 4. Dependence of relative water-level difference on main channel roughness and on ratio of main channel width to total width.

Conclusions

- The influence of main channel roughness on absolute water levels is significant, and can be up to 100 cm for a typical Dutch situation (α = 0.4).
- The influence of main channel roughness on relative water-level difference (dh/D_T) decreases for increasing discharge and floodplain width.
- Dependence on main channel depth is small (not shown).

The numerical computations will be compared with 2D WAQUA computations in future research.

Acknowledgements

This work is supported by the Dutch Technology Foundation STW, the applied science division of NWO, and the technology programme of the Dutch Ministry of Economic Affairs.

References

Huthoff, F. & D. Augustijn, 2004. Sensitivity analysis of floodplain roughness in 1D flow. In: S.Y. Liong, K.K. Phoon & V. Babovic (eds.), Proceedings of the 6th International Conference on Hydroinformatics, World Scientific Publishing Company, Singapore, pp. 301-308.

Julien, P.Y., G.J. Klaassen, W.B.M. ten Brinke & A.W.E. Wilbers, 2002. Case study: bed resistance of Rhine River during 1998 flood. Journal of Hydraulic Engineering 128 (12), pp. 1042-1050.

Van Velzen, E.H., P. Jesse, P. Cornelissen & H. Coops, 2003. Stromingsweerstand vegetatie in uiterwaarden; handboek versie 1-2003, RIZA report 2003.028/029, RIZA, Arnhem.

Wilbers, A., 2004. The development and hydraulic roughness of subaqueous dunes. Netherlands Geographical Studies 323, KNAG/Faculteit Geowetenschappen, Universiteit Utrecht, Utrecht, 227 p.

Effect of climate change on bedforms in the Rhine and consequences for navigation

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Abstract
Navigation on the river Rhine is of great economic importance for the Netherlands. Low river discharges or the presence of river dunes on the bed may restrict the water depth available for navigation. River dunes are bedforms that develop at high discharges, as a result of the interaction between flow and sediment transport. Dunes might hinder navigation as their development shows a delayed response to changing flow conditions, because it takes time for a dune to form or to degrade. This means that the maximum dune height is reached when the water depth is already decreasing. Therefore, it is important to know if river dunes will restrict the water depth significantly and whether climate change influences the development of river dunes in the Rhine. From the research it can be concluded that dunes do not significantly influence the hindrance of navigation, neither now, nor in the future.

Introduction
Many events, like more frequent flooding and extreme drought are addressed to a rising average global temperature. Several scenarios have been developed to forecast the possible consequences of this type of climate change for the Rhine basin. One of them is the UKHI scenario that is used to determine the expected discharges in the Rhine (Middelkoop et al., 2001). This scenario resulted in an increasing discharge in the Rhine in winter and a decreasing discharge in summer. As the development of river dunes depends on the discharge, it is important to know the effect on the dune development, in order to give insight in the effect of dunes on navigation.

Former research on river dunes in the Rhine showed that dunes of about 0.8 m are present at a discharge of 7,000 m^3/s. River dunes reach a height of about 1.6 m at an extreme discharge of 12,000 m^3/s (Wilbers, 2004). As a result of climate change, these dune heights might increase.
Next to that, erosion and sedimentation processes (Fig. 1), which play an important role in the dune development, take time. Consequently, river dune development responds to changing flow conditions with a time lag. This means that the maximum dune height is reached a few days after the peak discharge, when the water depth is already decreasing. This time lag could be relevant in the hindrance of navigation by river dunes.

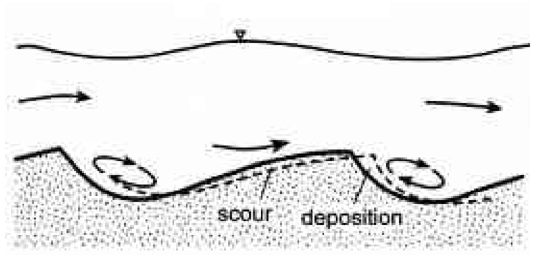

Figure 1. Process of erosion and sedimentation (after Knighton, 1998)

Method
In order to determine the effect of climate change on river dune development, the climate change scenario UKHI (United Kingdom Meteorological Office High Resolution General Circulation Model) was used. This scenario results in factors that can be multiplied with recorded discharges. Recorded discharges of three different years ('base years') with different discharge patterns and peak discharges were selected. Recorded and predicted discharges are used as input for a 1D-hydraulic model for unsteady flows, to compute corresponding water depths. These water depths were used in the calculation of dune heights, with the method of Wilbers (2004). This method is based on the ideas of Allen (1976) and has been specifically developed for the Rhine branches. In order to quantify the hindrance of navigation, the loading capacity of vessels is calculated based on the calculated water depths. This is done for the water depth with dunes and without dunes present.

Results
Climate change has a significant effect on the development of river dunes. Figure 2 presents the development of dune height in January for base year 2003 and for the expected dune

heights according to the UKHI scenarios for 2050 and 2100. A dune height of 1.2 m is calculated for a peak discharge of 9,000 m^3/s in the base year.
The UKHI 2100 scenario leads to a peak discharge of 14,000 m^3/s and the corresponding maximum dune height is 1.7 m.

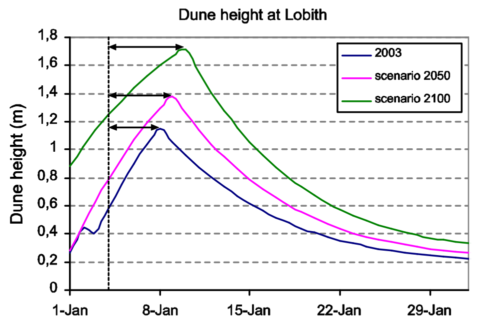

Figure 2. River dune development in base year 2003 and for the UKHI scenarios (vertical line represents the day of the peak discharge).

The time lag is clearly perceptible in the figure: the maximum dune height is reached later, while the peak discharge occurs on the same day. The maximum water depth at peak discharge is 14 m for the UKHI 2100 scenario. When the dune height is at its maximum, the water depth has decreased to 12 m, which is still large compared to the dune height of 1.7 m. Despite the delayed response of river dunes to changing discharges, the discharge does not decrease so quickly that the dune height becomes substantial compared to the water depth: after approximately one week the dune height is about 0.9 m, while the water depth is still about 9 m. It can be concluded that river dunes do not restrict the water depth for navigation during winter, because a low discharge does not occur very fast after a peak discharge. In other words: dunes get enough time to decay.

Figure 3 presents the loading capacity of vessels in time to get a better insight in the hindrance of navigation. It is clear that navigation is restricted by low flows in summer, when the discharge is about 900 m^3/s. The effect of climate change on the loading capacity is clearly perceptible; in September the loading capacity decreases from about 75% to about 55%. The influence of river dunes, however, appears to be insignificant: river dunes are calculated to be about 0.05 m high during summer. The restriction of the loading capacity by river dunes is only in the order of 1% (in Fig. 3 'with dunes' and 'without dunes') for the base year (1991) as well as for the UKHI 2100 scenario. Although climate change is expected to lead to higher river dunes, these higher river dunes do not further decrease the loading capacity of vessels.

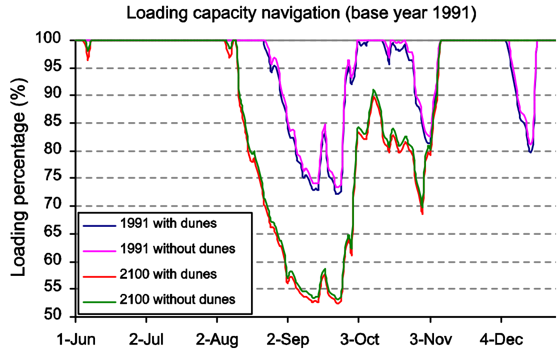

Figure 3. The effect of climate change and dune height on loading capacity.

Conclusions

It can be concluded that river dune development in the Rhine is strongly influenced by changing discharges, as a result of climate change. Higher discharges cause higher dunes and a larger time lag between peak discharge and maximum dune height.

Climate change does influence the hindrance of navigation during summer, due to a decrease of low discharges. However, dune height compared to water depth will always remain such that river dunes have no significant influence on the hindrance of navigation and this effect is not enlarged by climate change.

References

Allen, J., 1976. Bed forms and unsteady processes: some concepts of classification and response illustrated by common one-way types. Earth Surface Processes 1, pp. 361-374.

Knighton, A.D., 1998. Fluvial forms and processes; a new perspective, Arnold, London, 383 p.

Middelkoop, H., M. van Asselt, G. Können, S. van't Klooster, M. Haasnoot, W.van Deursen, N. van Gemert, J. Kwadijk, H. Buiteveld, P. Valkering, J. Rotmans, 2001. Integrated water management strategies for the Rhine and Meuse basins in a changing environment. National Research Programme on Global Air Pollution and Climate Change (NRP), Bilthoven.

Wilbers, A., 2004. The development and hydraulic roughness of subaqueous dunes. Netherlands Geographical Studies 323, KNAG/Faculteit Geowetenschappen, Universiteit Utrecht, Utrecht, 227 p

Navigability of the Niederrhein and Waal in the Netherlands; a stochastic approach

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Introduction

Half of the cargo transport between the port of Rotterdam and Germany goes via the Rhine. Safe, efficient and profitable inland shipping requires a deep and wide navigation channel, now and in the future. Navigability depends on morphological and hydraulic conditions in the river that exhibit spatial and temporal variations, such as bed level and water levels. Whenever the navigation depth is less than required, navigation is congested and/or ships may carry less cargo.

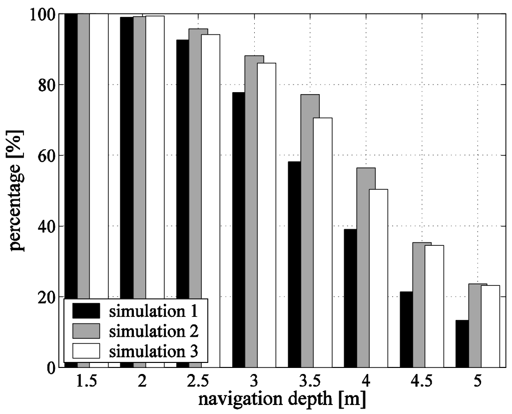
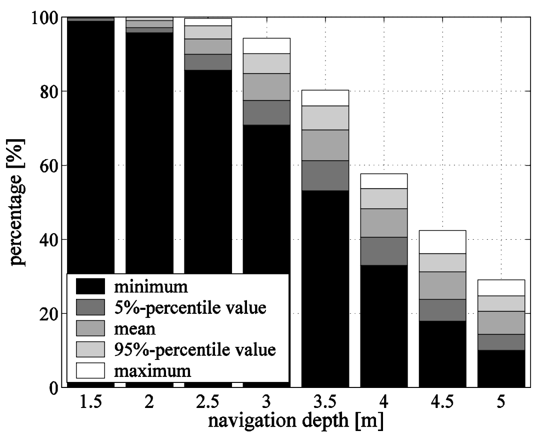


Figure 1. Percentage of navigable time as a function of the ship draft for the Niederrhein and Waal in the period between 2002 and 2012. Narrow bars represent individual simulations, whereas thick bars in other graph represent aggregates of all simulations.



Methods

A 1-dimensional morphodynamic SOBEK model of the Rhine (Jesse & Kroekenstoel, 2001) is used for water-depth predictions. These predictions, in combination with a theoretical correction for the transversal slope in river bends, are used to assess the navigability of the Niederrhein and Waal for ships of various drafts and make it possible to indicate nautical bottlenecks (the reach of the Niederrhein that is situated within the Netherlands is also known as the 'Boven-Rijn'). The Rhine model is affected by various uncertainties, including the model schematisations, the specification of the model input (for example boundary conditions, initial conditions) and the model parameters. Van der Klis (2003) and Van Vuren et al. (2002) have shown that the future discharge hydrograph is one of the important sources of uncertainty.

Monte Carlo simulation, applied to the model, is utilised to quantify the uncertainty in the water depth and thus navigability, given an uncertain river discharge. Monte Carlo simulation (Hammersly & Handscomb, 1964) involves a large number of model runs - 400 runs - with statistically equivalent inputs. For each run a discharge time series of 10-years duration is randomly generated using the Bootstrap-re-sampling technique (Efron, 1982). The outputs of these model runs, can be expressed in terms of expected development and uncertainty of the navigability, which provides insight into the stochastic characteristics of the river's navigability.

The National Traffic and Transportation Plan gives guidelines with respect to the navigation channel requirements. According to this plan, during discharges above a threshold value of 1020 m^3/s at Lobith (where the Rhine enters the Netherlands), the navigation channel in the Niederrhein and the Waal must have a guaranteed width of 170 m and a depth of 2.8 m, respectively. This threshold value is exceeded during 95 % of the time. The probability that these requirements are satisfied in the Dutch part of the Rhine for a period of 10 years is evaluated in this paper. The largest cargo ships in the Rhine have a draft of approximately 4 m.

Additionally, the navigability is assessed for drafts ranging from 1.5 to 5 m.

Results

The navigability of the Niederrhein and the Waal for ships with a draft between 1.5 and 5 m is statistically assessed on the basis of 400 model runs. Each model run driven by one of the synthesised discharge time series results in one possible future morphological evolution. Figure 1 (left diagram) shows that the navigable percentage in the 10-year period between 2002 and 2012 differs for each synthesised discharge time series. Using the results of all model simulations, the statistical characteristics of the navigable percentage are derived (Fig. 1; right diagram). For example, the percentage of navigable time for ships with a draft of 3 m at the Niederrhein and the Waal, averaged over a period of 10 years, is 84%. Figure 1 (right diagram) also shows that for this draft there is a 90% probability that the percentage of navigable time lies between 78% and 91%.

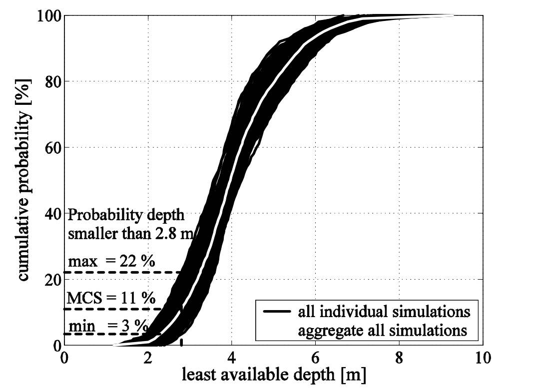


Figure 2. Cumulative probability distribution of the least available depth for all simulations individually (black lines) and the aggregate line (white line) together.

The probability of not fulfilling the navigation channel requirements of the National Traffic and Transportation Plan for ships at draft 2.8 m is of interest of both the river manager and the users of the inland waterway. This indicates how well the river manager maintains the required navigation condition. Figure 2 shows the cumulative distribution function of the least available navigation depth over a period of 10 years for all simulations individually and the aggregate line of all simulations together. The figure indicates the probability of meeting the requirements, i.e. ships can navigate at draft of at least 2.8 m, is 89.1 % (100 % minus 10.9 %) . The figure shows that this percentage of navigable time is at maximum 96.6 % and at minimum 77.9 % for the 400 model simulations considered herein.

Figure 3 illustrates the percentage of navigable time as a function of the river location for a draft of 2.8 and 4 m. This provides insight into which locations are critical to the navigability of the river. It appears that locations with strong spatial changes in geometry, such as the bifurcation Pannerdense Kop (km 867), the river bed protection in the river bend near Nijmegen (km 882 - 885), the variation in floodplain width in the Midden-Waal and the sharp bend at section Pannerdense Kop-Nijmegen and St.Andries, may evolve into navigation bottlenecks. Most of these bottlenecks become manifest in the dry period.

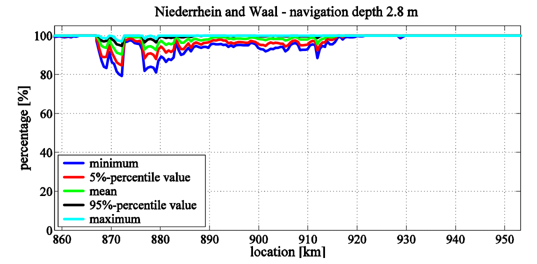
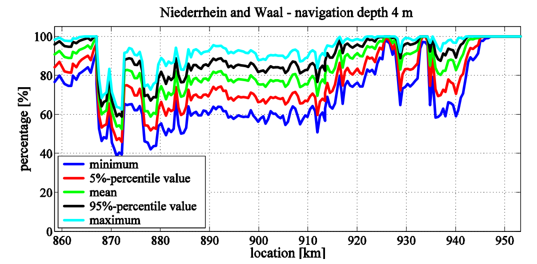


Figure 3. Percentage of navigable time over a period of 10 years as a function of the river location for ships of 2.8 m and 4 m draft.



Conclusion and future research

The foregoing showed that the water depth in the Niederrhein and the Waal exhibit a strong spatial and temporal variation. The uncertainty in the future discharge hydrograph, in combination with strong spatial variations in the river geometry, leads to significant uncertainties in the predicted response. Some locations could develop into nautical bottlenecks, the removal of which may involve high costs.

The stochastic method that is proposed in this paper could be used to assess the impact of various human intervention measures on the river's navigability. In addition to the expected impacts, the change in maintenance requirements (and so costs) can be assessed. This is subject of further research. We have used a 1-dimenional model in this study. This means that the impact of two-dimensional features, such as alternate bars and transverse bed slopes in bends, are not considered. Neither is the fact that large floodplain areas along the Rhine branches are located alternately at the right and the left side of the river, which under flood conditions may lead to strong 3-D cross-flows over the main channel. It is therefore recommended to repeat this kind of analysis with a model capable of describing these phenomena.

References

Efron, B., 1982. The Jackknife, the Bootstrap, and other resampling plans. Society for Industrial and Applied Mathematics. Philadelphia, 92 p.

Hammersly, J.M. & D.C. Handscomb, 1964. Monte Carlo methods. Methuen, Londen.

Jesse, P. & D.F. Kroekenstoel, 2001. 1-D Morfologisch model Rijntakken. RIZA rapport 2001.040, RIZA, Arnhem.

Van der Klis, H., 2003. Uncertainty analysis applied to numerical models of river bed Morphology. Ph.D. thesis, Delft University of Technology, Delft.

Van Vuren, S., H. van der Klis, & H. de Vriend, 2002. Large-scale floodplain lowering along the River Waal: a stochastic prediction of morphological impacts. In: D. Bousmar & Y. Zech. (eds.), Proceedings of River Flow 2002; volume 2, Balkema, Rotterdam, pp. 903-912.

Stochastic modelling of two-dimensional river morphology

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Abstract
Uncertainty in the results of a 2-D river morphological model of the Upper Rhine due to the uncertainty in the river discharge is estimated by applying a Monte Carlo simulation. As a possible more efficient alternative, the applicability of the Quasi Monte Carlo method is studied. First results of the convergence rate of statistical quantities of the river bed are promising. Based on these results, further research on this subject has been planned.

Introduction
The importance of knowledge of uncertainties in model results is more and more recognised by river managers. The quantification of these uncertainties, however, is often difficult. In this research we focus on a specific aspect of this problem, applied to a 2-D river morphological model: quantifying the uncertainty in the model results due to uncertain inputs. Thus, we leave uncertainties in the model structure and the modelling context out of consideration.

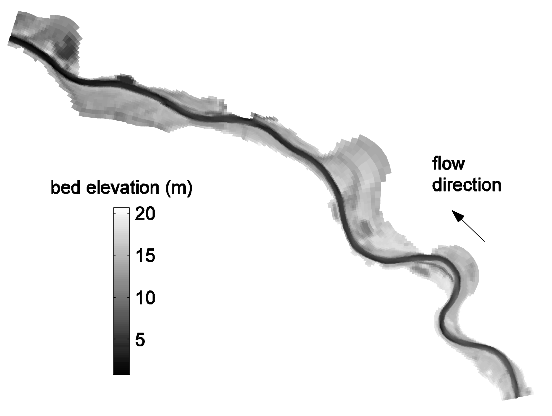

Figure 1. Overview of the morphological Delft3D model.

A (non-linear) river morphological model generally requires a Monte Carlo-like approach to estimate the uncertainty in the model results due to uncertain model input (Van der Klis, 2003). Such an approach is robust and much statistical information can be obtained from the results. An important disadvantage of the method, however, is the number of model simulations required. In case of the large, computational intensive models we talk about, a standard Monte Carlo (MC) simulation is practically impossible. Therefore, we search for alternative Monte Carlo approaches which lead to drastic decrease in the required number of simulations.

As a case study, we choose an existing 2-D river morphological model, namely a Delft3D model of a reach of the Upper Rhine (Baur et al., 2002). The model schematisation includes floodplains such that their effect during high discharges is represented in the model (Fig. 1). The model area has a length of 42 km.

A Monte Carlo simulation
A MC simulation consists of a large number of deterministic simulations, of which the uncertain model input is randomly generated according to prescribed probability distributions. The output values constitute random samples from the probability distribution of the output. Standard statistical techniques can be used to estimate the statistical properties of the model output and the precision of the output distribution.

We carried out 100 simulations, each forced at the upper boundary by a randomly drawn 3-years discharge series. In order to sample discharge series, we derived a statistical description of the Rhine discharge at Lobith. We based the statistical description of the Rhine discharge on daily discharge data from 1946 to 2000 following the method previously applied by Van Vuren et al. (2002).

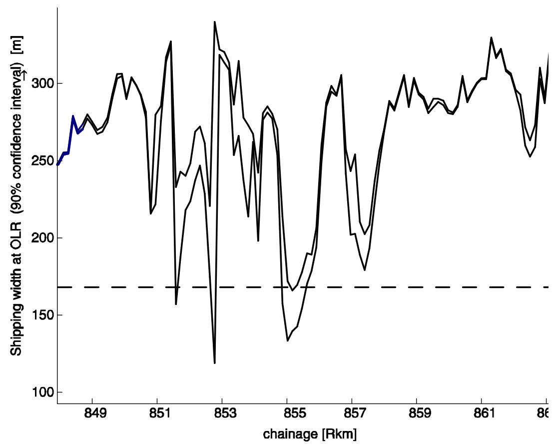

Figure 2. The 90% confidence interval of the shipping width (area between the two lines) based on a minimum water depth of 2.8 m during OLR-conditions.

The MC simulation results in an estimate of the effect of the uncertainty in the river discharge on the river bed changes in the model. Figure 2 shows an example of the information that can be obtained: the 90% confidence interval of the shipping width in a part of the modelled river reach. This type of information can help a river manager to decide where problems might occur for shipping.

An alternative: Quasi Monte Carlo

The sampling method used in a standard MC simulation is rather inefficient: in order to double the accuracy of the estimate of the output uncertainty, four times the number of samples is required. Many alternative sampling methods have been developed to improve the efficiency of the Monte Carlo simulation. In this study, we examine the applicability of the so-called Quasi Monte Carlo (QMC) approach to our case study.

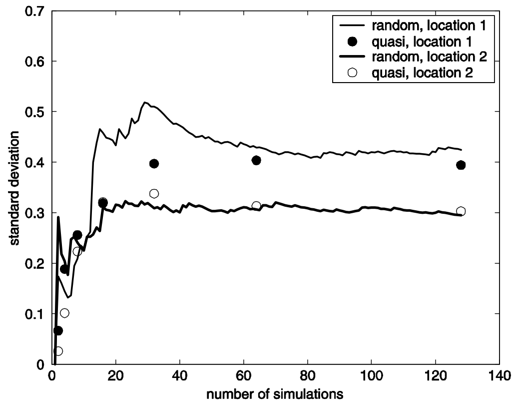

Figure 3. Convergence rates of the standard deviation of the river bed level at two locations within the main channel, both for the random MC simulation and the quasi MC simulation.

The QMC method is the deterministic version of the standard Monte Carlo method, in the sense that the random samples in an MC simulation are replaced by well-chosen deterministic points. Various methods have been developed to create sequences of those deterministic points. Often applied is the Sobol sequence, or LP_τ sequence. Homma & Saltelli (1995) compared the efficiency of various sampling methods and showed an evident advantage of using the LP_τ sequence.

This gives us sufficient ground for examining the applicability of the method to a river morphological model.

To test QMC to our case study, we simplified the description of the discharge series following Chapter 4 in Van der Klis (2003). With this simplified description we performed a QMC simulation and, for comparison, a standard MC simulation. Figure 3 illustrates the convergence rate of each of these methods. For two locations within the main channel of the modelled river reach the convergence of the standard deviation of the bed level is shown. This figure shows a relatively fast convergence of the QMC results.

Conclusions and further research

The first results presented here are promising enough to further explore the possibilities of QMC in our model. In this, we will try to apply the method to more advanced descriptions of the river discharge. Furthermore, we will study whether QMC is applicable to other uncertain model parameters.

Acknowledgement

The model of the Upper Rhine and the discharge measurements have been made available by RWS, DON and RIZA.

References

Baur, T., H. Havinga & D. Abel, 2002. Internationale Zusammenarbeit bei der Planung von Regulierungsmaßnahmen am Niederrhein: Durchführung flussmorphologischer Simulationen, HANSA International Maritime Journal 10/2002, pp. 51-56.

Homma, T. & A. Saltelli, 1995. Use of Sobol's Quasirandom sequence generator for integration of modified uncertainty importance measure. Journal of Nuclear Science and Technology 32(11), pp. 1164-1173.

Van der Klis, H., 2003. Uncertainty analysis applied to numerical models of river bed morphology. Ph.D. thesis, Delft University of Technology, Delft.

Van Vuren, S., H. van der Klis & H.J. de Vriend, 2002. Large-scale floodplain lowering along the river Waal: a stochastic prediction of morphological impacts. In: D. Bousmar & Y. Zech (eds.), Proceedings of River Flow 2002, Volume 2, Balkema, Rotterdam, pp. 903–912.

Sediment density stratification and river channel patterns in the lower Yellow River, China

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Abstract
The lower Yellow River is characterised by a braiding channel pattern, which changes into a meandering pattern in the downstream direction. Although the bed-level gradient is important for this transition, the sediment concentration plays an additional role. At low sediment concentrations the flow is sub-saturated, leading to a meandering pattern. At higher concentrations the turbulent structure of the flow is suppressed and the sediment concentration profile collapses, leading to a braiding channel pattern. At even higher sediment concentrations, sediment is held in suspension by hindered settling, and the channel pattern becomes increasingly meandering.

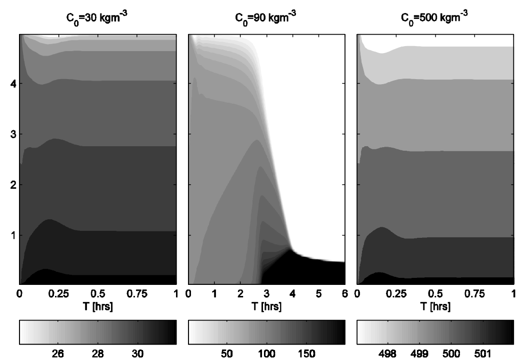

Figure 1. Evolution of vertical sediment concentration profile during sub-saturated (C = 30 kg/m^3), supersaturated (C = 90 kg/m^3), and hyperconcentrated sub-saturated (C = 500 kg/m^3) flow conditions. The flow velocity is 2 m/s and the grain size 40 microns.

Introduction
The Chinese Yellow River carries huge amounts of suspended sediment, especially during hyperconcentrated floods when sediment concentrations exceed 100's kg/m^3. A large part of this sediment load is deposited in the lower Yellow River, leading to a rapidly rising floodplain and therefore increasing flood risks. In order to manage these siltation problems a 3D morphodynamic model is being developed for the lower Yellow River within Delft3D.
However, the sediment concentration in the Yellow River is so high that sediment density stratification is important for sediment transport mechanisms and river morphology. The relationship between these stratification processes and river channel patterns will be described here shortly.

Vertical sediment density stratification
At low sediment concentrations, the downward motion of sediment particles is balanced by a net upward transport of sediment by turbulent motions, resulting in a typical Rouse sediment concentration profile. However, at high concentrations (order 1's to 10's kg/m^3, depending on the grain size) these turbulent motions are suppressed by the sediment concentration gradient (Winterwerp, 2001). Therefore the turbulent motions are no longer able to hold sediment in suspension and at a critical sediment concentration, the sediment concentration profile collapses: the flow changes from sub-saturated into super-saturated flow. At even higher sediment concentrations (order 10's to 100's kg/m^3), sediment is additionally held in suspension by hindered settling. Therefore the sediment concentration profile is re-established even though turbulence is low: sub-saturated hyperconcentrated flow (Winterwerp et al., 2003). This collapse and build-up of the vertical sediment concentration profile can be simulated with a 1DV version of Delft3D model that includes sediment density effects (Fig. 1). The sediment concentration at which the sediment concentration profile collapses or is re-established is the saturation concentration. This saturation concentration initially increases with the (dimensionless) flow strength [u^3/ghw_0 in which: u = depth-averaged velocity (m/s), g = gravitational acceleration (m/s^2), h = water depth (m), w_0 = sediment settling velocity in clear water (m/s)], but decreases when hindered settling effects become important. This means that at very high sediment concentrations, the flow strength required to keep sediment in suspension is low. Numerically modelled relations between flow strength and saturation concentration matches sediment concentrations observed in the Yellow River (Fig. 2).

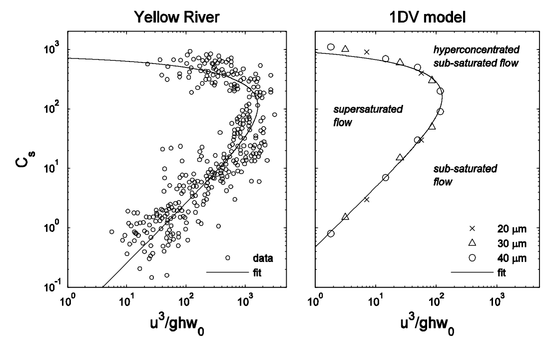

Figure 2. Relationship between dimensionless flow strength u^3/ghw_0 (see text for explanation of symbols) and saturation concentration C_s in the Yellow river (left panel) and based on 1DV results (right panel). Flow velocities during the 1DV simulations ranges from 0.5 to 3 m/s, and the D_{50} between 20 and 40 microns.

River channel patterns

The upper part of the Yellow River is braiding, but changes into a meandering pattern in the downstream direction. And although this transition mainly results from a decreasing bed level gradient, field observations show that the Yellow River becomes increasingly meandering at concentrations below 30 kg/m^3 and above 200 kg/m^3, and braiding at intermediate concentrations (Xu, 2004). However, the reasons for this behaviour are not yet fully understood. The super-saturated flow conditions described in the previous section are characterised by deposition, whereas the sub-saturated flow conditions are characterised by bed erosion. This strongly suggests that the vertical sediment density effects discussed in the previous section are important for the morphology of the Yellow River. To verify this, 3D modelling experiments were carried out to identify the effect of hyperconcentration on the development of river morphology. Starting with an initially flat but randomly perturbed bed, a braiding river channel develops during relatively low sediment concentrations (upper panel in Fig. 3).

However, when an additional wash load fraction of 100 kg/m^3 is included (hyperconcentrated flow), a meandering channel pattern begins to develop (lower panel in Fig. 3).

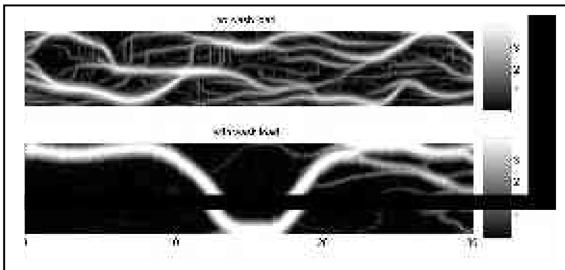

Figure 3. Channel development after approximately one year in an initially flat bed using a slope of $2.2 \cdot 10^{-4}$, a discharge of 5000 m^3/s, and sediment with $D_{50} = 65$ microns. X-axis and Y-axis are in km and the water depth in m. The simulations in the upper panel are without a wash load fraction whereas a wash load fraction with C=100 kg/m^3 and $D_{50} = 5$ microns is included in the lower panel. Although this wash load fraction does not interact with the river bed, it results in hyperconcentrated flow and consequently a strongly incising meandering channel.

Conclusions

The Yellow River channel pattern partly depends on the sediment concentration with a meandering pattern at low and high sediment concentrations, but a braiding pattern at intermediate concentrations. This is caused by sediment density stratification, and can be numerically simulated with Delft3D.

References

Winterwerp, J.C., 2001. Stratification effects by cohesive and non-cohesive sediment. Journal of Geophysical Research 106, pp. 22.559-22.574.

Winterwerp, J.C., H.J. de Vriend & Z.B. Wang, 2003. Fluid-sediment interactions in silt-laden flow. Proceedings of the First International Yellow River Forum on River Basin Management, Zhengzhou, China, 21-24 October 2003, Vol. II. Yellow River Conservancy Publishing House, Zhengzhou, pp. 351-362.

Xu, J., 2004. Double thresholds in scour-fill processes and some implications in channel adjustment. Geomorphology 157, pp. 321-330.

Causal relationships between climate change and natural river behaviour in the Rhine delta during the last 15,000 years

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Abstract
The Rhine delta in the Netherlands developed during the last 15,000 years under influence of tectonics, sea-level rise and, most importantly, the sediment flux from the hinterland. Changes in this sediment flux since the last Glacial-Interglacial transition, appear to be mainly related to changes in climate, land use and vegetation in the upstream part of the catchment, causing variations in sediment delivery from the German part of the basin (e.g. Berendsen et al., 1995, Vandenberghe, 1995). This Ph.D.-project (2004-2007) focuses on the relationship between upstream sediment delivery in the Rhine drainage basin and downstream sedimentation in the delta as a result of vegetation changes since the end of the Weichselian.

Introduction
Natural river behaviour, i.e. sedimentation dynamics and fluvial style, in a delta area is controlled by several factors (Fig. 1). Allogenic influences on fluvial systems at drainage basin scale and on the time scales of 1,000 to 100,000 years are tectonics, climate and sea level-change. Although tectonics and sea level do have large effects on fluvial systems such as the river Rhine, climate (temperature and precipitation) ultimately controls river discharge and sediment supply and, thereby, the dynamics and size of sediment fluxes in a fluvial system. Beside climate change, land-use changes have a direct impact on the vegetation cover and hence, subsoil cohesion and effective runoff. All this results in variations in discharge and sediment load of the river Rhine in time, and eventually, in variations in downstream sedimentation dynamics and fluvial style.

Although a relationship between natural changes in climate, vegetation, and sediment delivery in the upstream area and the associated sedimentation downstream in the delta is obvious, this relationship has never been quantified.
With the current amount of data present in the whole drainage basin, it is now timely to make the link between upstream erosional phases and downstream sedimentation in order to obtain a better insight in the evolution of the delta and to determine causal relationships between climate change and natural river behaviour.

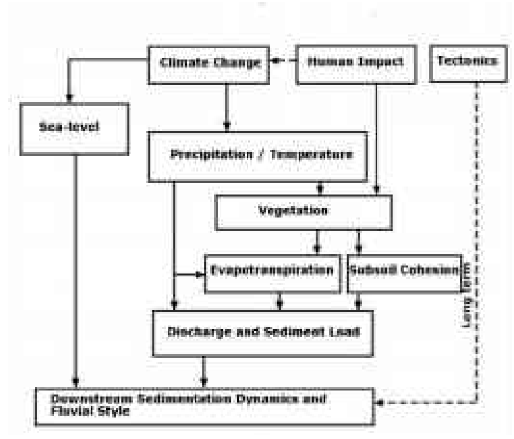

Figure 1. Factors controlling sedimentation dynamics and fluvial style in a delta area

Approach
The Netherlands is in the unique position of having a near-complete capture of the Rhine sediment flux within the Rhine-Meuse delta for the later part of the Holocene (Berendsen & Stouthamer, 2001). Decades of palaeogeographic research makes the Rhine delta now one of the best-studied deltas in the world. This research enabled a detailed palaeogeographic reconstruction of the Dutch Rhine-Meuse delta during the last 15,000 years (Berendsen & Stouthamer, 2001). With the data from the extensive Rhine-Meuse delta database, three large north-south sections (length: ca. 20 - 50 km) were constructed. Together with two already existing sections (Törnqvist, 1993; Cohen, 2003) and complementary data, these sections will be used to obtain a detailed (100 m core spacing) Holocene stratigraphy, showing distinct differences in accumulation rates. A large number of radiocarbon dates provide time lines in these sections. Subsequently, deposited volumes of Rhine sediment during the last 15,000 years in the Rhine delta can be

calculated per time slice, providing depositional rates.

During the last 15,000 years, climatic change induced large-scale changes in vegetation in the German part of the Rhine drainage basin. Several regional German studies show a distinct human impact on the landscape from 6400 cal yrs BP onward, leading to vegetation change and enhanced soil erosion (e.g. Lang et al., 2003). Because there is a strong link between vegetation and fluvial dynamics (e.g. Dambeck & Thiemeyer, 2002), vegetation changes are likely to have caused variations in upstream sediment delivery in the Rhine drainage basin. Phases of (increased) siliciclastic input in the German part of the basin will be determined and correlated with phases of downstream deposition, in the Rhine delta. It is expected that changes in sediment discharge during the last 15,000 years can be linked to climate change and, for the last 5000 years, increased human impact.

Perspectives and relevance

Changes in land-use and climate are likely to affect rivers and their catchments during the next centuries, altering flows of water and sediment, which will have a large impact on the Rhine delta in the Netherlands. For the river Rhine, modelling results suggest a more frequent occurrence of abnormal low and high discharges in the near future. In addition, suspended sediment concentrations in the river are expected to increase due to an increased production of sediment by soil erosion (Middelkoop, 1997).

These future changes will be superimposed on changes triggered in the past. Therefore, a better understanding of (past) fluvial responses to land-use and climate change is needed. Until now, most research has been conducted in small catchments, while the response of large catchments has a more comprehensive impact, which is especially relevant for the Netherlands. The time period over which a large catchment responds to land-use or climate change is much longer than for small catchments and much longer than most instrumental time series. This means that palaeoenvironmental reconstructions are essential, because only these reconstructions provide a record of catchment responses on century to millennia time scales.

Quantifying the link between upstream erosional phases and downstream sedimentation in the Rhine drainage basin, will improve our insight in the evolution of the delta, including the causal relationships between (future) climate and land-use changes and natural river behaviour.

References

Berendsen, H., W. Hoek & E. Schorn, 1995. Late Weichselian and Holocene river channel changes of the rivers Rhine and Meuse in the Netherlands (Land van Maas en Waal). Paläoklimaforschung-Paleoclimate Research 14, pp. 151-172.

Berendsen, H.J.A. & E. Stouthamer, 2001. Palaeogeographical development of the Rhine-Meuse delta, The Netherlands. Van Gorcum, Assen, 250 p.

Cohen, K.M., 2003. Differential subsidence within a coastal prism; Late Glacial – Holocene tectonics in the Rhine-Meuse delta, The Netherlands. Netherlands Geographical Studies 316, KNAG/Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht, Utrecht, 176 p.

Dambeck, R. & H. Thiemeyer, 2002. Fluvial History of the northern Upper Rhine river (southwestern Germany) during the Lateglacial and Holocene Times. Quaternary International 93/94, pp. 53-63.

Lang, A., H.-R. Bork, R. Mäckel, N. Preston, J. Wunderlich & R. Dikau, 2003. Changes in sediment flux and storage within a fluvial system: some examples form the Rhine catchment. Hydrological Processes 14, pp. 3321-3334.

Middelkoop, H., 1997. Embanked floodplains in the Netherlands; Ggeomorphological evolution over various timescales. Netherlands Geographical Studies 224, KNAG/Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht, Utrecht, 341 p.

Törnqvist, T.E., 1993. Fluvial sedimentary geology and chronology of the Holocene Rhine-Meuse delta, The Netherlands. Netherlands Geographical Studies 166, KNAG/Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht, Utrecht, 176 p.

Vandenberge, J., 1995. Timescales, climate and river development. Quaternary Science Reviews 14, pp. 631-638.

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13M-2001 "Interactive Flood Management and Landscape Planning in River Systems" - User Manual version 1.0.0

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